RADIO and RADAR ASTRONOMY

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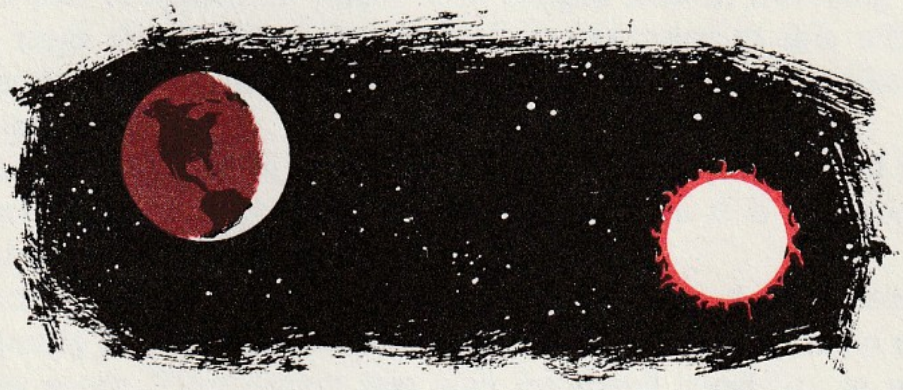

SCIENCE PROGRAM

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Science Service

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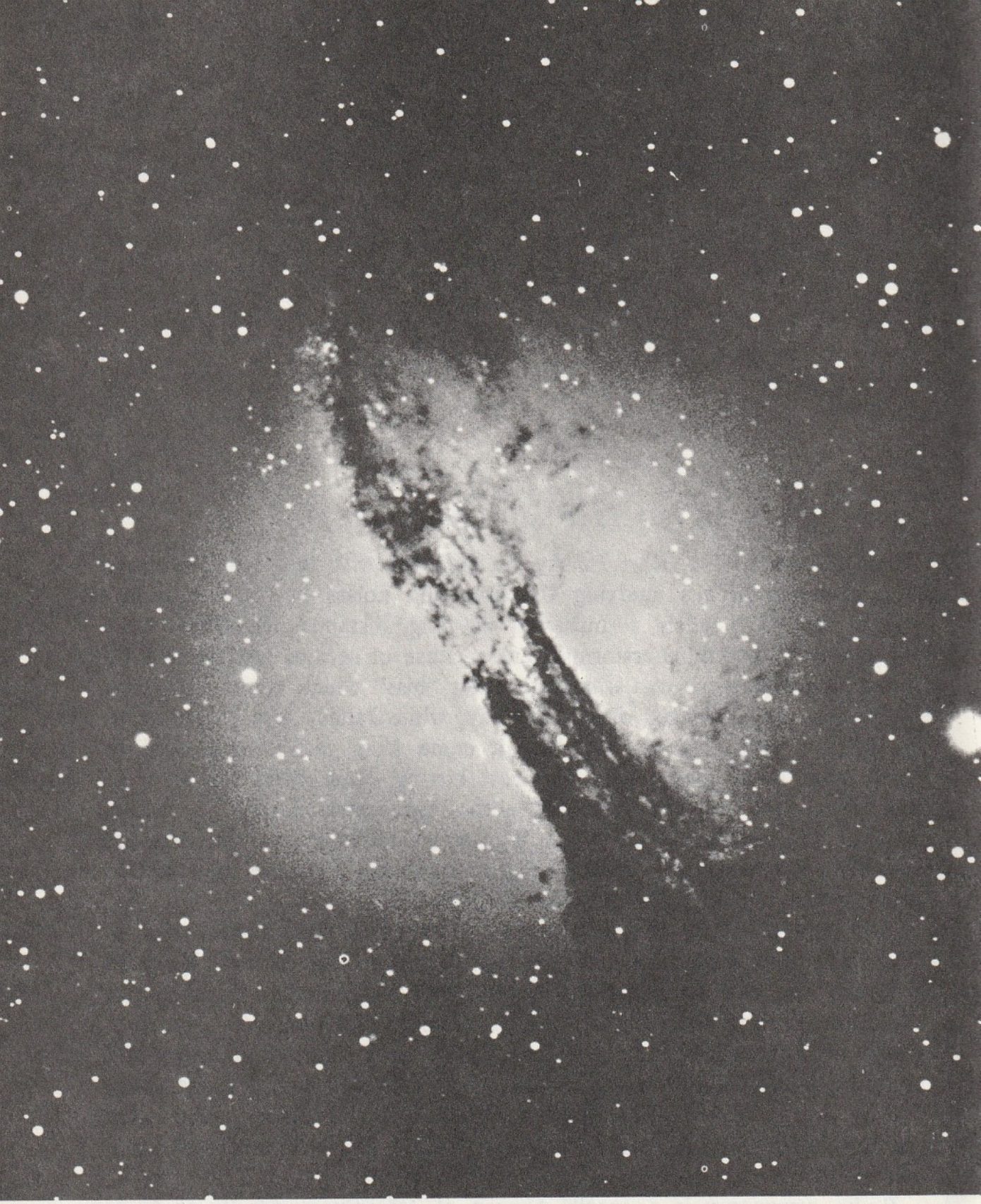
What Is Radio Astronomy?

In 1930 and 1931, Karl Jansky, an engineer with the Bell Telephone Laboratories, was studying the crackling noises or "atmospherics" which are often such a nuisance in long distance telephone calls. Jansky knew that thunderstorms were a cause of serious trouble, but he also found that there was a strange, faint "hiss" which could always be heard. This hiss changed during the day, while Jansky was recording it. By 1932 it was clear to him that it came from radio waves sent to earth from outer space. The strongest hissing came from the stars of Sagittarius (the Archer), which lie across the central part of the Milky Way. If this meant that the Milky Way was a radio transmitter, then the radio waves must have been travelling to the earth for more than 25,000 years at the rate of 186,000 miles a second!

How this could be was a mystery, yet the only person who tried to solve it was an American amateur radio "ham", Grote Reber. He built what we now call a radio telescope and with it he studied even shorter radio waves from the Milky Way than Jansky had observed. After six years' work he was able to show that Jansky was right; radio waves did come from the Milky Way, very short waves as well as the longer ones Jansky had received. The studies by Jansky and Reber, who used special radio antennas and receivers, marked the beginning of radio astronomy.

Radio astronomy is a special branch of astronomy, yet its study is now a really important part of the whole science. Without radio astronomy our knowledge of the universe would not be as complete as it is—yet without ordinary "optical" astronomy our radio observations would mean much less than they do. One helps the other, and this is

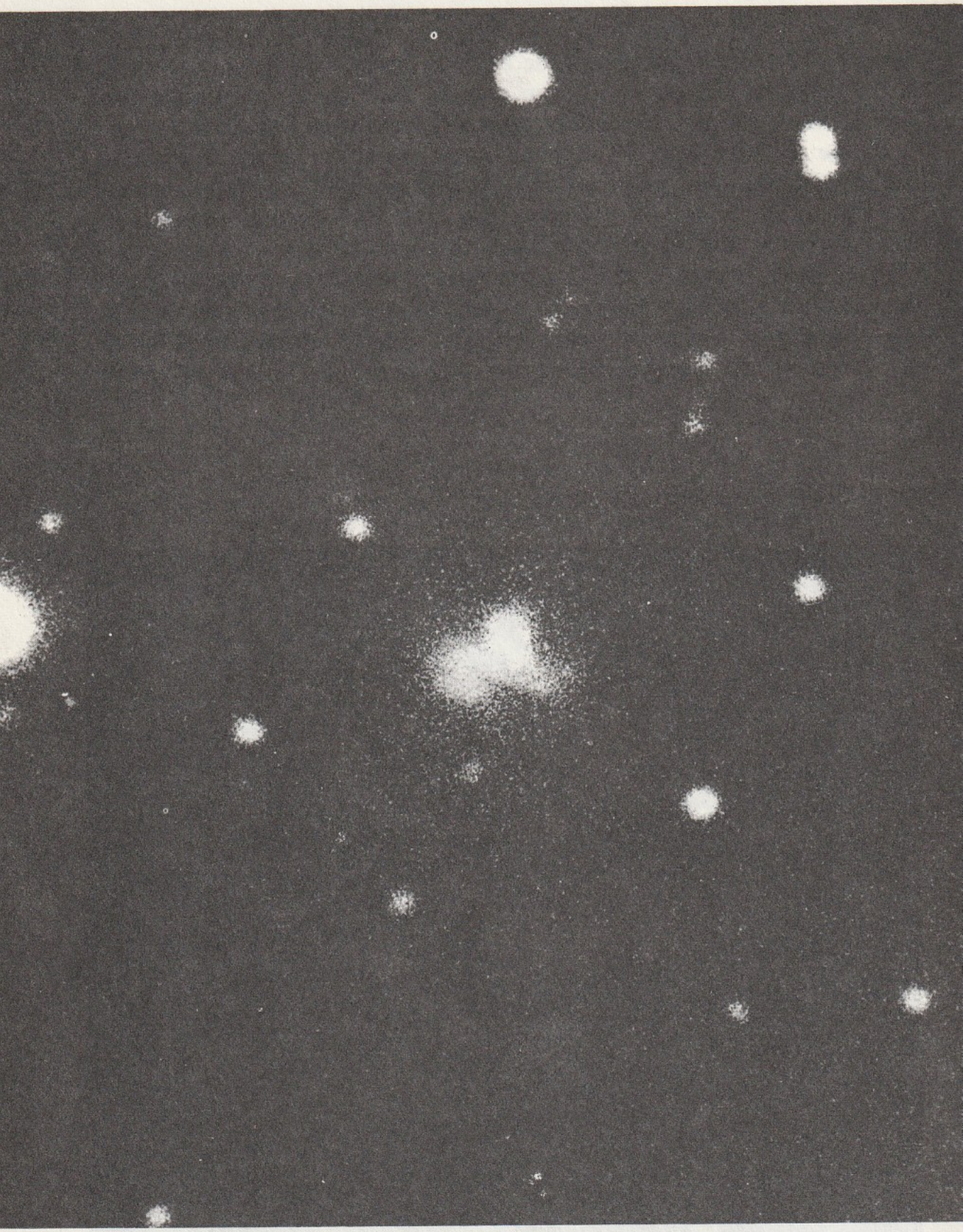


This giant object in space, known as NGC 5128, may be two galaxies in collision and is a powerful radio source.

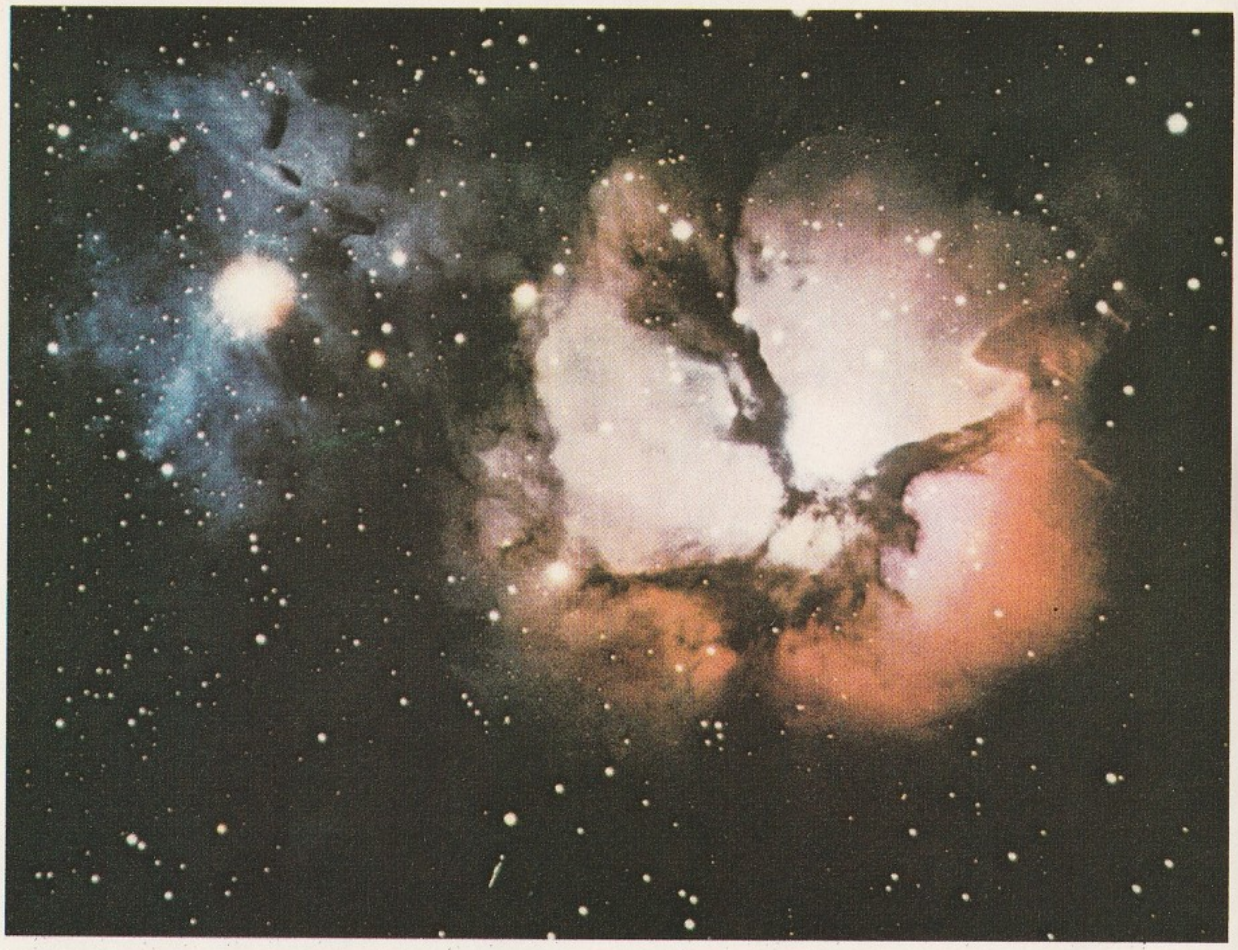
because our direct knowledge of the universe comes only from our studies of the radiation sent out to us from planets, stars, clouds of glowing gas, star islands or galaxies, interstellar molecules, pulsars and quasars.

All the radiation from the celestial bodies travels to us across space at incredible speed—the speed of light. At this speed of a little more than 186,000 miles per second, radiation only takes 1⅓ seconds to reach us from the moon and about 8½ minutes to come from our nearest star—the sun. From the other stars it takes from 4⅓ *years* to reach us—from the nearest at hand—to thousands of years from the more distant ones in our own galaxy. Yet astronomers can now observe galaxies from which the radiation has been travelling for thousands of millions of years.

A far-ultraviolet photograph of the Large Magellanic Cloud taken by the Naval Research Laboratory's Far-Ultraviolet Camera/Spectrograph.



A 200-inch photograph of Cygnus "A"—a most powerful radio source.

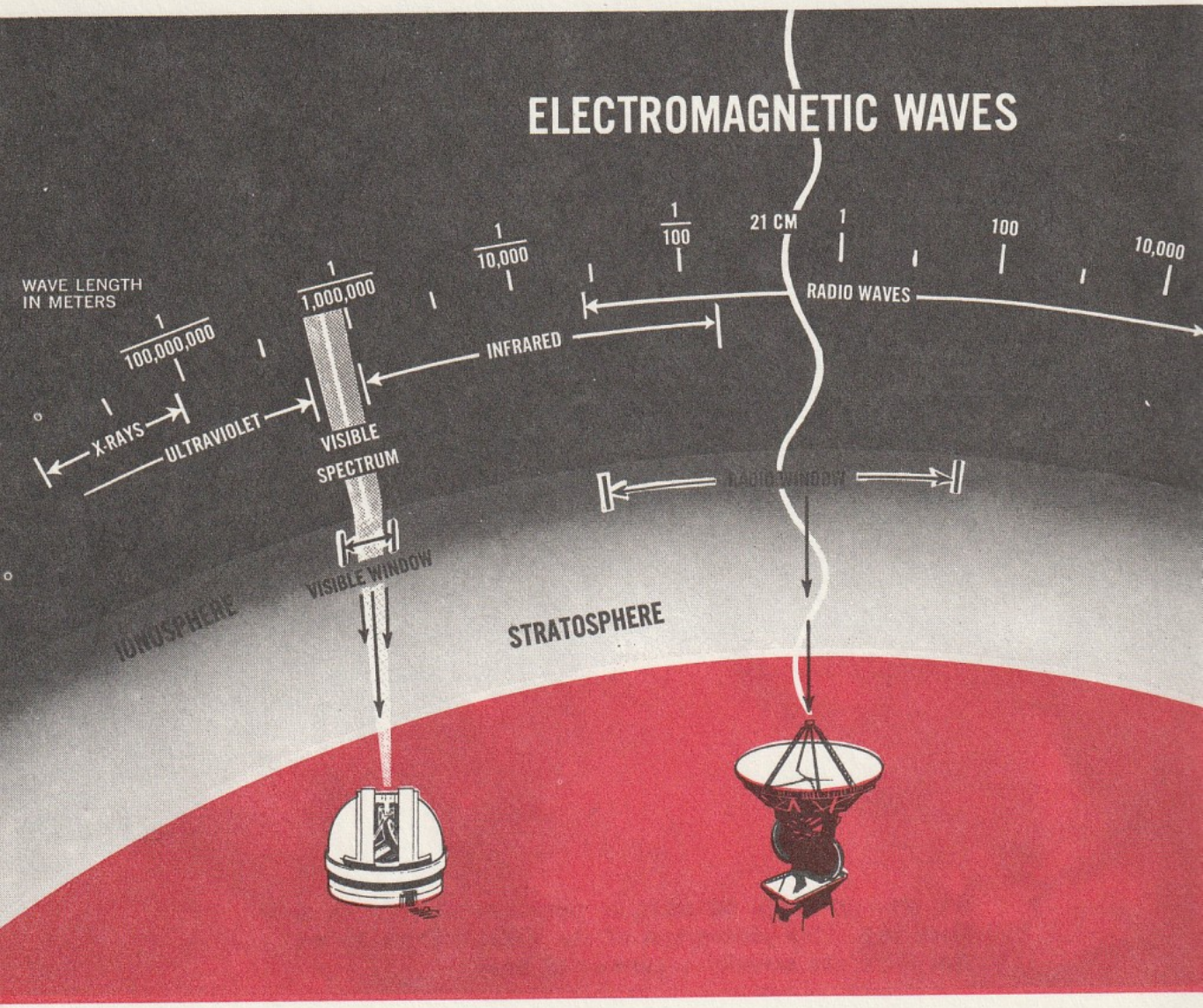


1. TRIFID NEBULA IN SAGITTARIUS

We tend to think of stars as pinpoints of light in a black sky. This photograph of the Trifid Nebula shows that there are actually a number of hues.

Most of the radiation from celestial bodies with which we are familiar is the light we see. We recognize the sun and the daylight which accompanies it, the moon because it reflects the light of the sun and shines in the night sky, and the stars because they themselves shine and seem to be bright points of light. Yet visible light is not the only electromagnetic radiation which celestial bodies emit.

When we consider all types of this radiation as waves, then we find that the difference between one type of radiation and another is only one of wavelength. The wavelength of radiation of any type is the distance between one "crest" of the wave and the next crest. The shortest

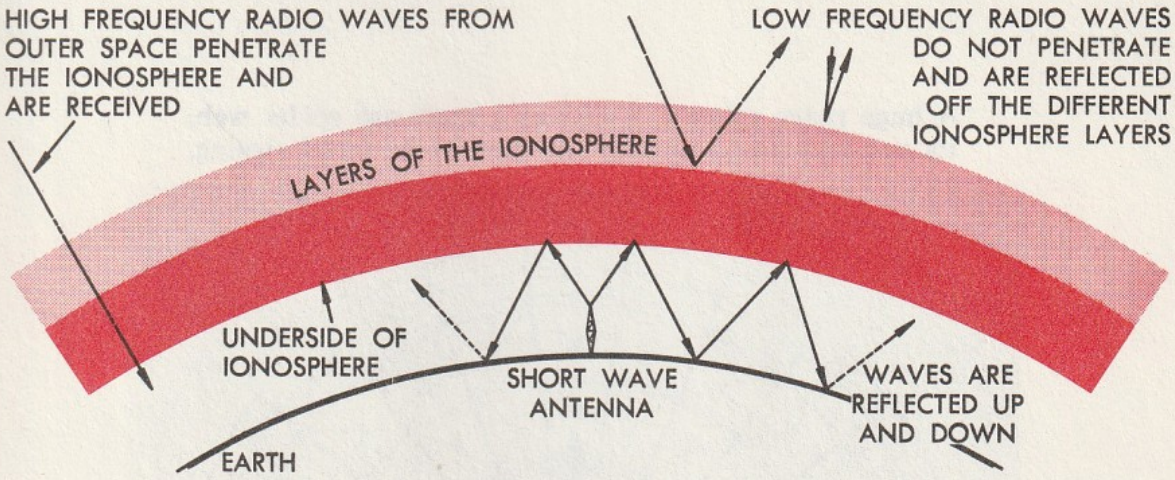


wavelengths, known as gamma rays, are so small that the wavelength is less than about one-hundred-millionth of a centimeter. Next come X rays, some of which are not greater than one-millionth of a centimeter from crest to crest. Ultraviolet rays are longer, and their wavelength can be as much as four-millionths of a centimeter. We can see none of these wavelengths because our eyes are not sensitive to them, yet our skins are affected by ultraviolet—which shows up as sunburn—and X and gamma rays can affect both our skin and the living cells in our bodies.

Light is the name of those wavelengths which we can see. Wavelengths of forty-millionths of a centimeter give violet light, wavelengths of fifty-

millionths are blue-green, sixty-millionths seem yellowish-orange, and wavelengths of between sixty- and eighty-millionths give red light. Wavelengths from eighty-millionths to one-hundredth of a centimeter we again are unable to see, but our bodies are sensitive to them and we recognize them as "heat". Light is the radiation by which, in the past, we mainly observed the universe. But it is only a very small fraction of the whole range of radiation which the heavens emit. The fact that we are now able to observe in radio wavelengths means that we can extend our knowledge. Because radio waves can penetrate fog, mist and clouds, we can also observe radio waves from space in weather which stops visual observation.

THE EARTH'S IONOSPHERE


HIGH FREQUENCY RADIO WAVES FROM OUTER SPACE PENETRATE THE IONOSPHERE AND ARE RECEIVED
LOW FREQUENCY RADIO WAVES DO NOT PENETRATE AND ARE REFLECTED OFF THE DIFFERENT IONOSPHERE LAYERS
LAYERS OF THE IONOSPHERE
UNDERSIDE OF IONOSPHERE
SHORT WAVE ANTENNA
WAVES ARE REFLECTED UP AND DOWN
EARTH

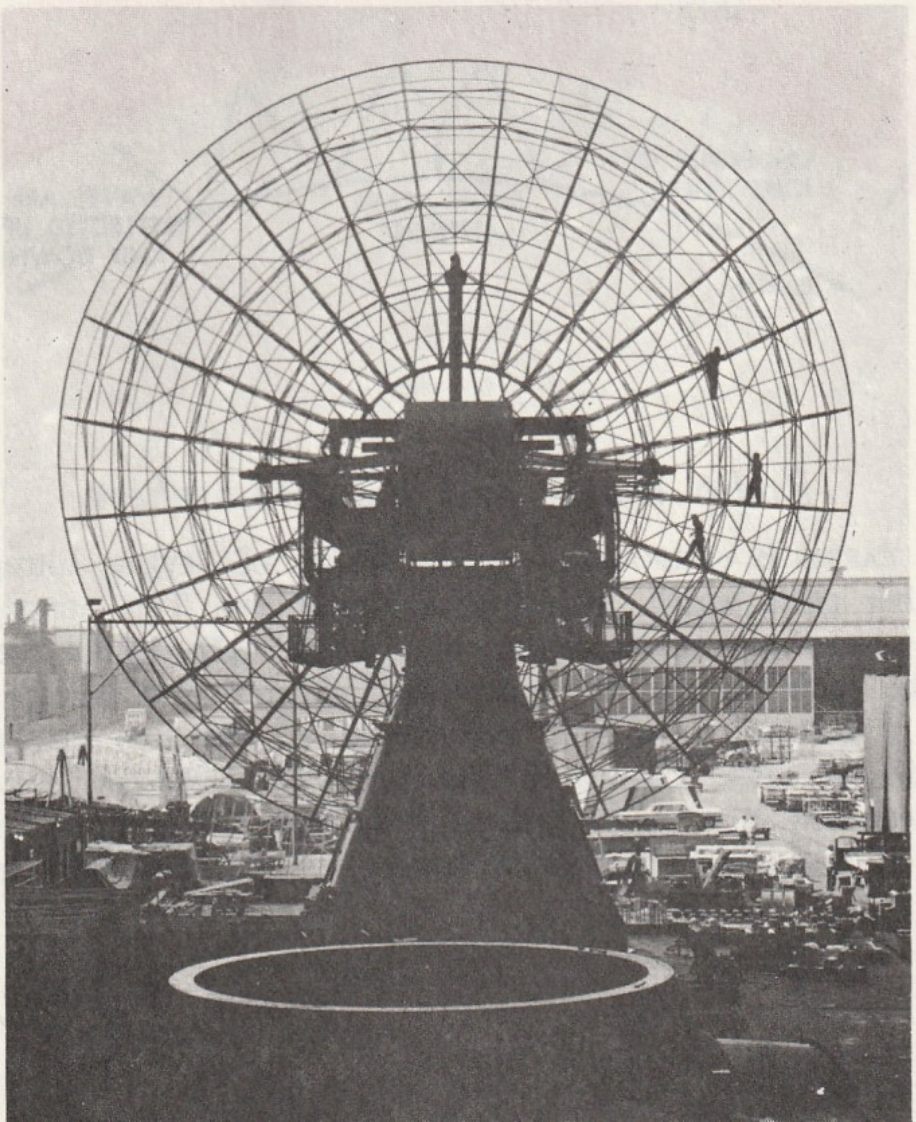
Radio Waves and the Atmosphere

OUR EARTH IS SURROUNDED by a blanket of oxygen, nitrogen and other gases which make up its atmosphere. This atmosphere is thickest near the ground and becomes increasingly thinner the higher above the earth we go. The composition changes with altitude. At an altitude of 200 miles the air is still affected by radiation from the sun. This radiation causes the air particles to be electrified, or ionized. Another electrified layer lies between ninety and 150 miles up and yet another at about sixty-three miles above the ground. These layers of

ionized air act as mirrors and reflect radio waves. The two top layers reflect the shorter radio waves, and the lower layer at sixty-three miles acts as a mirror to the longer ones. There is also another electrified layer which behaves in a rather irregular fashion; this lies at a height of about forty-five miles.

These electrified layers—known as the *ionosphere*—are very important to radio communication on earth and also affect the radio waves which come from outer space. For ordinary radio communication the ionosphere acts as a mirror high in the sky and reflects back to earth the radio waves sent out by a radio station. This means that short-wave radio can cover the world, the short waves being bounced off the ionosphere back to earth, bounced to the ionosphere again, and so on right around the globe.

A huge radar antenna resembles a space-age spider web. Its size may be gauged by the men in its metal rigging.



The ionosphere not only acts as a mirror to radio waves from earth, it also reflects back into space some of the radio waves which head for earth from other celestial bodies. Because of this we can say that the ionosphere acts as a filter to radio waves coming in to the earth from outside, allowing only some to reach our radio telescopes.

The earth's atmosphere also acts as a filter. Nearer to the ground than the ionosphere lie oxygen and water vapor which absorb any really short radio waves coming from space. Because of these effects of the atmosphere and the ionosphere it is impossible, without using space-borne instruments, to study all the radio wavelengths which head for earth from outer space. The wavelengths that can readily be studied range from a little under a centimeter to a few meters, and this part of the whole band or "spectrum" of radiation is sometimes called the "radio window". There are also narrow windows around four and eight millimeters.

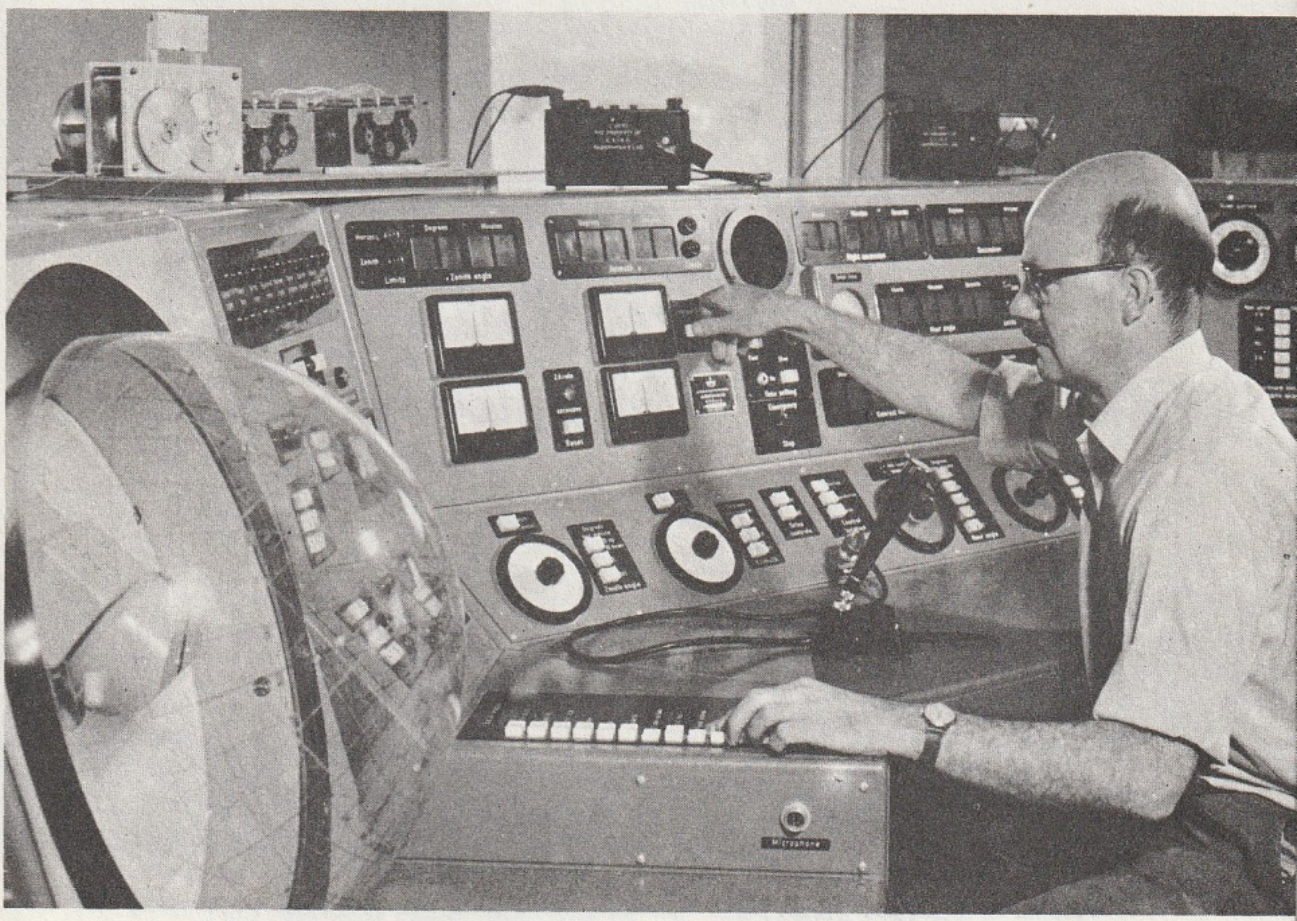
Besides reflecting longer radio waves, the upper parts of the ionosphere sometimes affect those radio wavelengths which do get through. This is due to "clouds" of electrified particles moving about, clouds which cannot be seen but which are noticeable in radio telescopes as a kind of "twinkling" or scintillation of the radio waves from celestial bodies.

Receiving Radio Waves

IN A RADIO TELESCOPE, the part played by the receiver is equivalent to that of the photographic plate at the focus of an optical telescope. The equipment now used for most radio astronomy observations is quite complex. However, it consists essentially of an antenna to gather the radio waves and feed them into a receiver where they are greatly amplified. The amplified energy operates a recording device, which is equivalent to the loudspeaker in a home radio. A tiny radio transmitter that emits only local signals is also part of the system, and is used as an alternate to the antenna in order to verify the performance of the receiver.

The system described is very similar to the receiving portion of a radar system, with the television-like display screen used with radar being replaced by the device to record the current picked up by the antenna. Immediately after World War II, scientists converted many surplus radar antennas for use as radio telescopes.

Radio telescopes are very sensitive and are very prone to pick up



This is the control desk inside the concrete base tower of the Australian telescope at left.

unwanted interference from earthly sources as well as the wanted cosmic or solar radio waves. The basic method for recognizing radiation as coming from a non-earth source is that its direction of arrival remains fixed in space, and it does not share distortions caused by the rotation of the earth. This was the criterion used by Jansky in his pioneer identification of galactic radio waves.

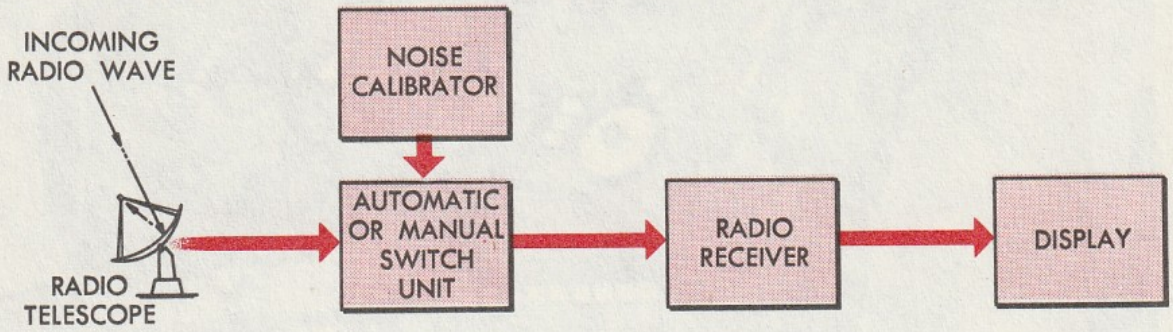
All known extra-terrestrial sources give a well-known and easily identified swishing sound like that characteristic of receiver noise. Crackles, crashes, clicks and other similar random noises appear to come only from earthly sources. Although it is helpful to be able to identify and

(*Left*) A giant Australian radio telescope with its dish tilted down to maximum depression.

ignore man-made interference, it is much more effective to choose a site for the radio telescope where such unwanted radio waves are reduced to a minimum.

New kinds of receivers, with very much improved sensitivity, have been developed since World War II. Both the MASER, which stands

ESSENTIAL ELEMENTS IN A RADIO ASTRONOMY SYSTEM

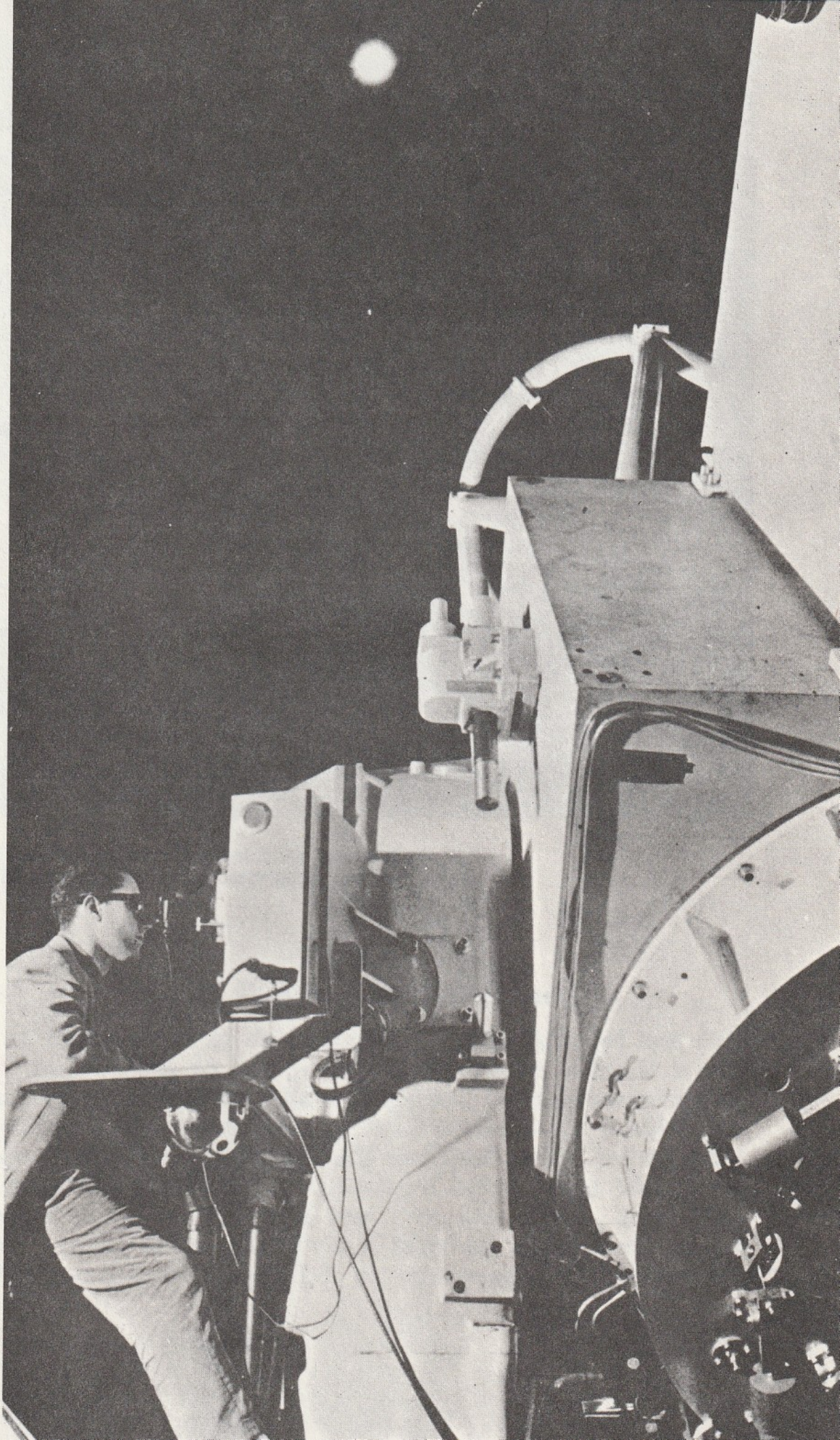


The radio telescope receives and focuses radio waves. A switch, manually or automatically operated, selects either these signals or the signals from a noise calibrator and sends them to the radio receiver. The receiver then relays to a metering device: a loudspeaker, or an oscilloscope display for visual interpretation, or a pen and ink recorder for a permanent record.

for *M*icrowave *A*mplification by *S*timulated *E*mission of *R*adiation, and the parametric amplifier give improvements in sensitivity of many, many more times than that available with conventional amplifiers.

The MASER used with radio telescopes is frequently a piece of crystalline ruby held at a very low temperature in a magnetic field. The ruby can store energy that it later emits as a radio wave oscillation, either strongly when it is stimulated to do so, or slowly and at random under normal conditions. The stimulation comes from a radio wave of exactly the same frequency as that emitted by the crystal.

(*Right*) In 1962, a team at Massachusetts Institute of Technology used an optical MASER to bounce light back from the moon. The reflection from the moon was not visible, but was recorded electronically. Part of double telescope system is seen here with the moon in background.

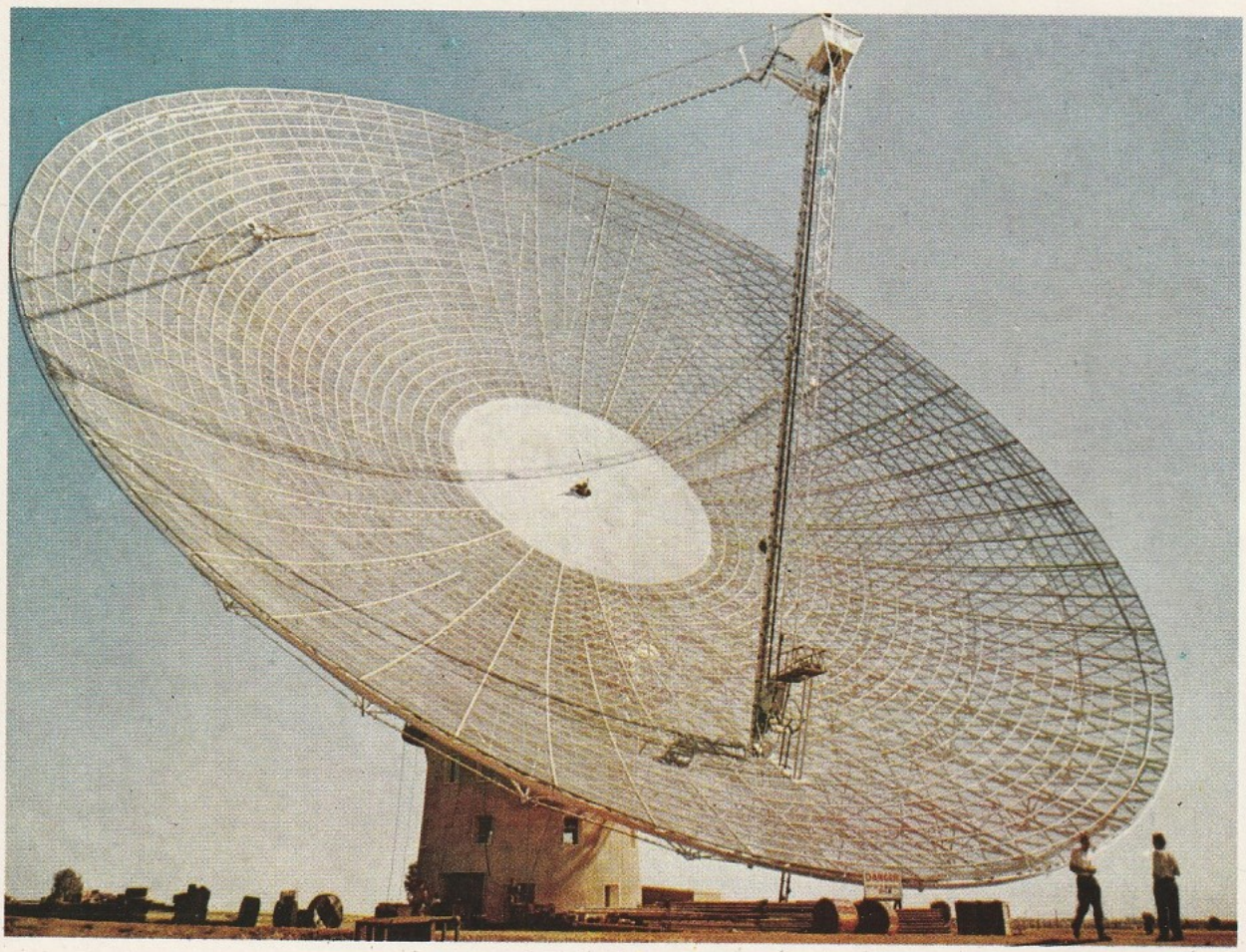


The word "parametric" in parametric amplifier implies that amplification is achieved by a change in the parameters. Unlike MASER action, in this case the oscillation is mechanical. It can be likened to the case of a child who "works" himself higher and higher on a swing by shifting his weight to produce a rhythmic, repeating change in his moment of inertia. Electrically, the parameter that is changed is usually the capacitor of a condenser; that change is induced by an oscillator, called a "pump".

Radio Telescope Antennas

A RADIO RECEIVER, however careful its design and construction, is of no use for radio astronomy unless fed with signals from an antenna. In radio astronomy the antennas have to gather as much as they

Not the largest radio telescope in the world, but probably the most powerful, is the giant dish in New South Wales, Australia. It is more powerful because it has greater surface accuracy.



3. AUSTRALIA'S RADIO TELESCOPE

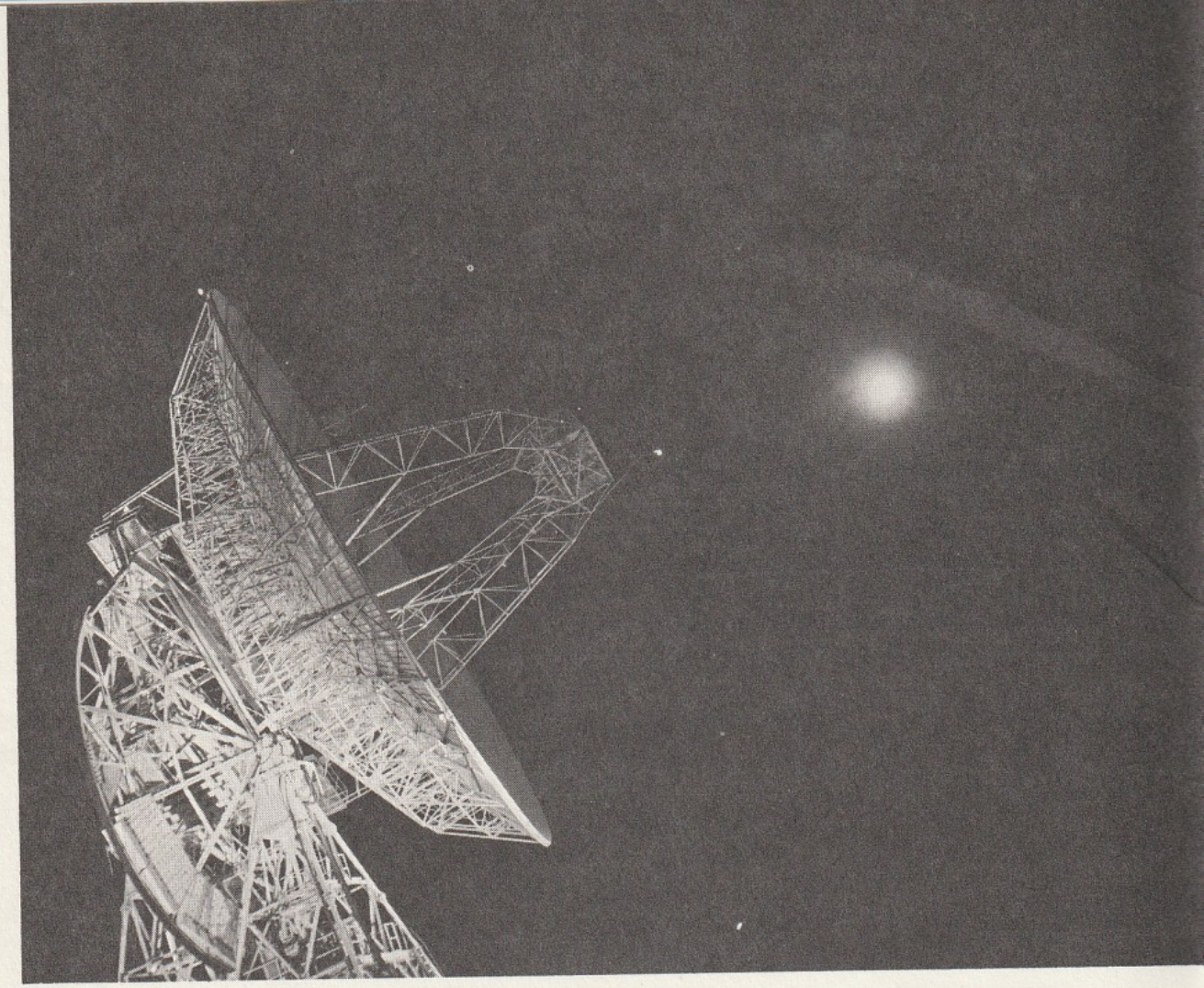
Shown while still under construction, the huge dish of the Jodrell Bank radio telescope stands out against the twilight sky. The moon, also visible, was first impacted by Lunik II in 1959 and this telescope confirmed the hit. In 1969 it recorded a Soviet impact on Venus.

4. JODRELL BANK

can of the radio waves from celestial objects; also, they have to gather in waves from only one direction in the sky. To achieve this the antennas often have to be spectacular in size and are the big "dishes" people usually imagine when they think of radio telescopes.

Because optical telescopes gather all the light they can from a small part of the sky, we might well expect that radio telescope antennas, which have to do the same for radio waves, could be made rather like an optical telescope in shape, and we would be correct. The most powerful optical telescopes are giant reflecting telescopes with a huge curved mirror at one end. The rays of light from stars and other celestial bodies strike the mirror and are reflected to a point or focus. The antennas or radio telescopes act in a similar way—the radio waves from celestial bodies strike a curved reflector and are reflected to a focus where there is a special short-wave antenna.

In an optical telescope, the mirror is made of glass and coated with a film of aluminum, but in a radio telescope the reflector does not have to



A partial phase of the 1970 solar eclipse is seen as it passed over the eighty-five-foot tracking antenna at Wallops Station, Virginia.

be either so smooth or so dense as glass. This is because the radio waves are much longer than light waves. The result is that some radio telescope reflectors are made of sheets of copper fixed together so that they form a curved surface and some, for the longer radio waves of a meter wavelength or more, can be and are made of wire netting stretched over a curved frame. The long radio waves are too big to "slip through" the holes in the netting.

(*Right*) Many radio and radar telescopes have reflectors that consist of wire netting stretched over a parabola-shaped frame.

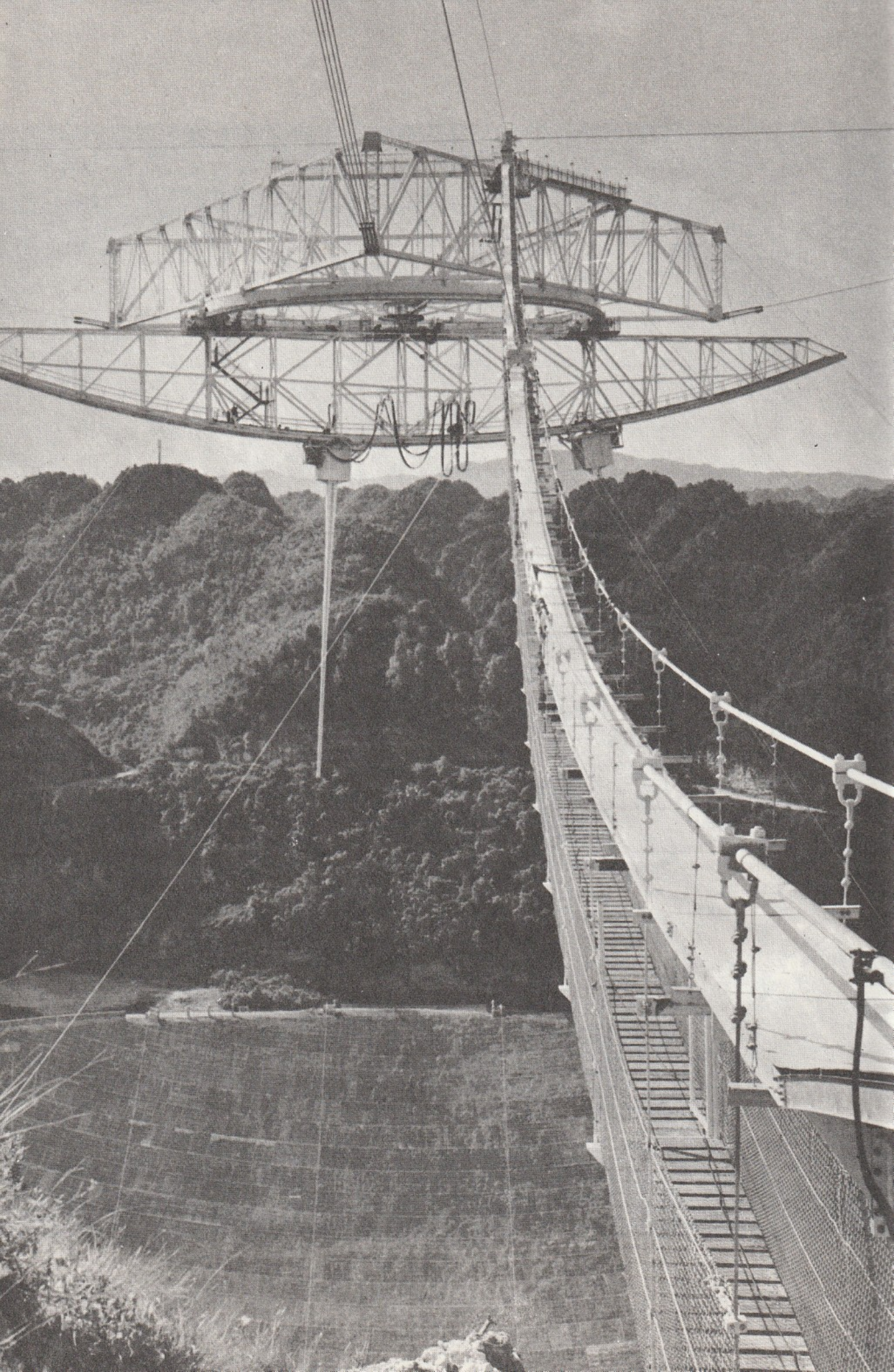
At the focus of the radio telescope reflector is a radio antenna which is coupled to the radio receiver. In most radio telescopes this antenna takes the form of a *dipole*—that is, an antenna made up of two metal rods fixed end to end, with a piece of "insulating" material which cannot conduct electricity, in between. The total length of these rods together is equal to half the wavelength of the radio waves being received. An FM antenna is of this type, and so is a television antenna. However, a television antenna looks different because it is made up of two dipoles, the extra one to increase the antenna collecting area and to allow reception of different stations at widely different frequencies.

In radio telescopes for very short wavelengths, the reflector passes the radio waves directly down a metal tube or waveguide, the size of which depends on the wavelength. No dipole is needed. Sometimes, where strong signals from the sun are to be received, a dipole is used with a number of metal rods forming a reflector, and no curved "mirror" is required. However, the curved mirror of wires or copper plates is the most usual kind of reflector, and the huge radio telescopes at Sydney in Australia, at Jodrell Bank in England, and at California and West Virginia in the United States are of this type.

As the earth spins each day on its axis, so the sky seems to spin about the poles of the heavens—the celestial poles. The result is that, except to an observer at the north or south poles, the stars always appear to move in a curved path across the sky. To follow them with a telescope we have to move our telescope around and elevate it up or down at the same time. Astronomers have found this inconvenient, especially when observing for hours on end, and have devised an "equatorial" mounting. In such mounting one of the axes about which the telescope pivots points to the celestial pole, and is called the "polar axis". Once the telescope has been set on a star, then pivoting about the polar axis keeps the telescope in its correct position. Such a mounting is very large but with it only one motion is required to follow a star.

Many radio telescopes are built on equatorial mountings, but the very largest ones are too big to be set up in this way. In these the mountings are often of the simpler kind which have to make two motions in order

(*Right*) The giant dish in New South Wales, Australia, shown under construction.

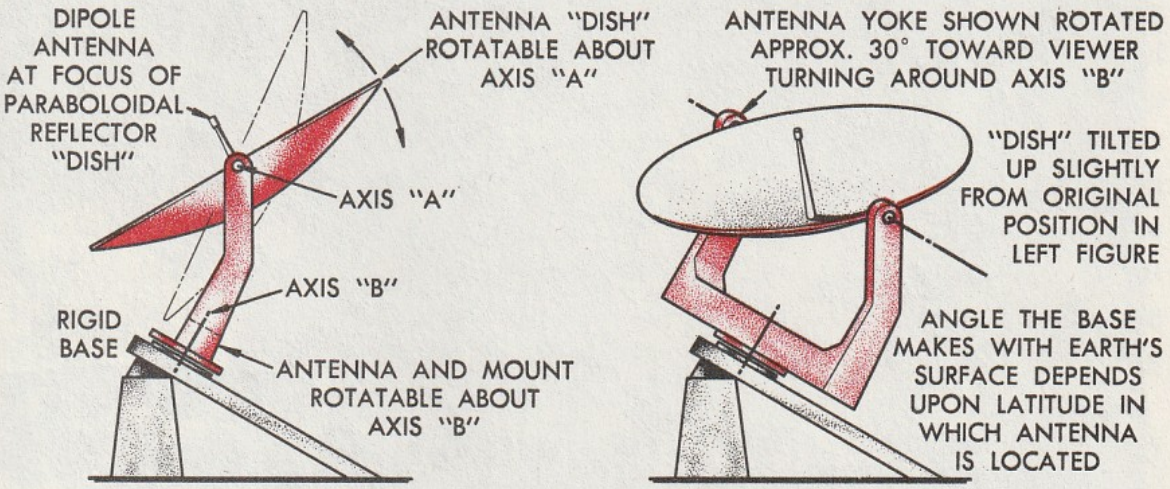


to follow the stars, and are known as "alt-azimuth" mountings. The two motions are worked out by an electronic computer so that the disadvantages for an observer are largely overcome. The simplest mounting of all, and used for some special radio telescopes, allows the antenna to pivot only in a north-south direction, pivoting in the east-west direction being carried out by the daily rotation of the earth itself.

Using an "Interferometer"

IT IS IMPORTANT to radio astronomers for their telescopes to be able to pick out and study only a small portion of the sky. A small bowl reflector cannot be made to cover an area as small as that of a larger

EQUATORIAL MOUNTING


DIPOLE ANTENNA AT FOCUS OF PARABOLOIDAL REFLECTOR "DISH"
ANTENNA "DISH" ROTATABLE ABOUT AXIS "A"
AXIS "A"
AXIS "B"
RIGID BASE
ANTENNA AND MOUNT ROTATABLE ABOUT AXIS "B"
ANTENNA YOKE SHOWN ROTATED APPROX. 30° TOWARD VIEWER TURNING AROUND AXIS "B"
"DISH" TILTED UP SLIGHTLY FROM ORIGINAL POSITION IN LEFT FIGURE
ANGLE THE BASE MAKES WITH EARTH'S SURFACE DEPENDS UPON LATITUDE IN WHICH ANTENNA IS LOCATED

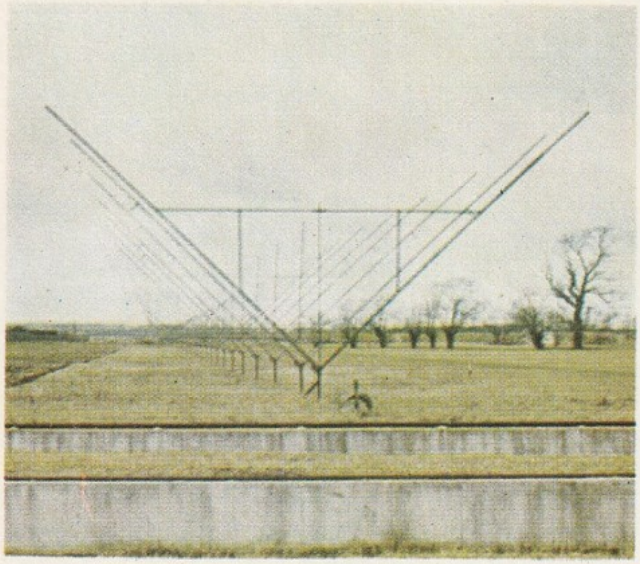
reflector, and the larger the reflector of a radio telescope, the more nearly it is possible to "pinpoint" that part of the sky from which radio waves are being received. Even so, the picking-out or "resolving power" of a radio telescope is nowhere near as good as that of an optical tele-

(*Left*) Part of the largest radio dish telescope in the world, at Arecibo, Puerto Rico.

The 140-foot telescope at the National Radio Astronomy Observatory, Green Bank, West Virginia.

scope. The 250-foot reflector at Jodrell Bank, England, for example, has a resolving power less than 1/3000 as good as an ordinary observatory telescope.

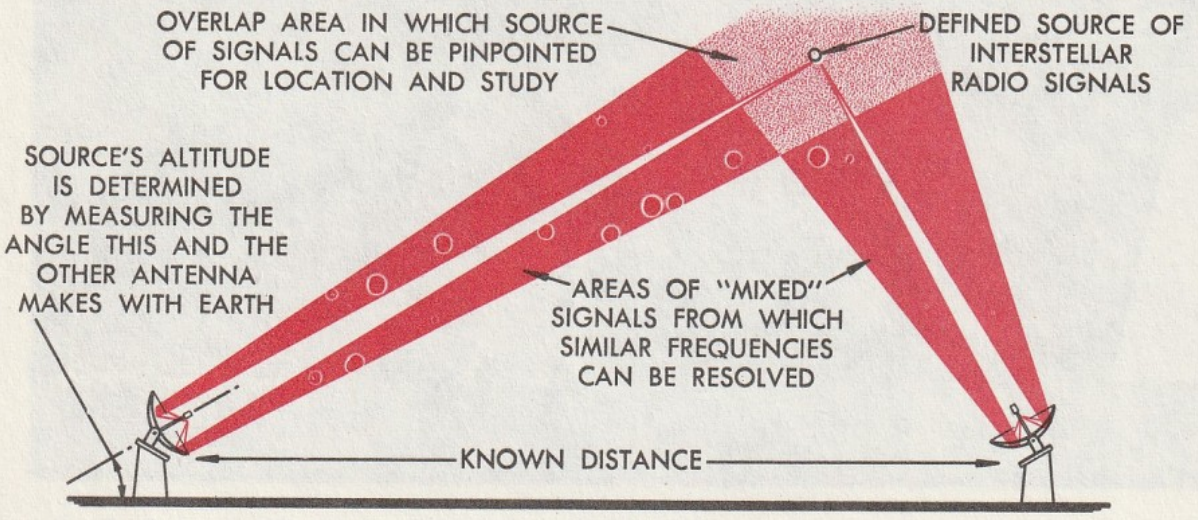
The resolving power of a radio telescope can be much improved by making what is known as an "interferometer". Here, two or more radio telescopes are used at once, and the radio waves received by each are



5. INTERFEROMETER ANTENNA

This long antenna array forms part of the interferometer system at the Mullard Radio Observatory in England. It stretches for half a mile.

AN INTERFEROMETER SYSTEM


OVERLAP AREA IN WHICH SOURCE OF SIGNALS CAN BE PINPOINTED FOR LOCATION AND STUDY
DEFINED SOURCE OF INTERSTELLAR RADIO SIGNALS
SOURCE'S ALTITUDE IS DETERMINED BY MEASURING THE ANGLE THIS AND THE OTHER ANTENNA MAKES WITH EARTH
AREAS OF "MIXED" SIGNALS FROM WHICH SIMILAR FREQUENCIES CAN BE RESOLVED
KNOWN DISTANCE

Parallel aiming of antennas is essential with stars at such distances.

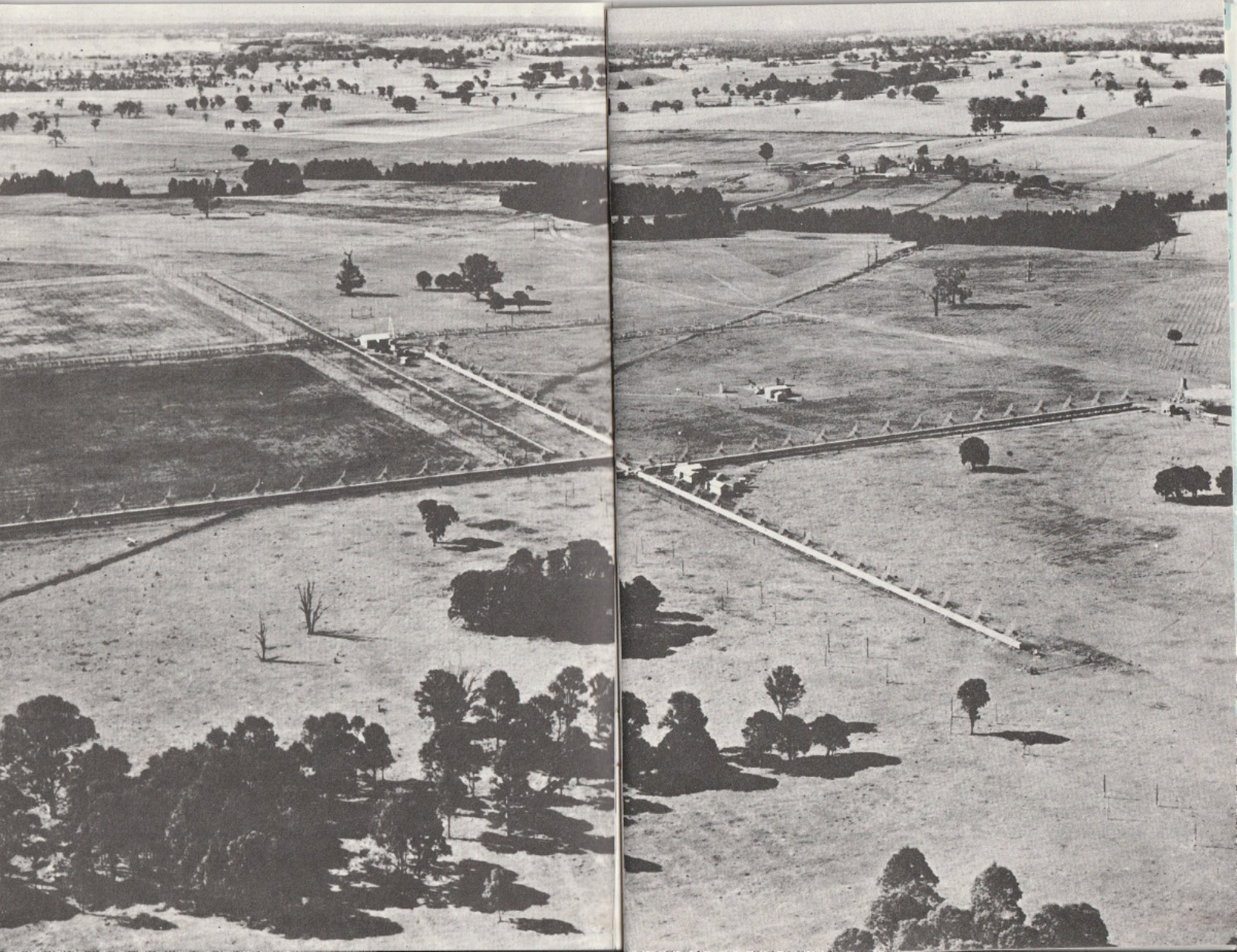
mixed together so that they interfere with one another. The result is that it seems to the radio astronomer that he has a radio telescope with much larger antennas. Using an interferometer, he can separate radio sources in space impossible for him to resolve using one antenna only. He can also measure how much area of the sky is covered by each source, and he can pick out radio sources from a "noisy" background of radio waves.

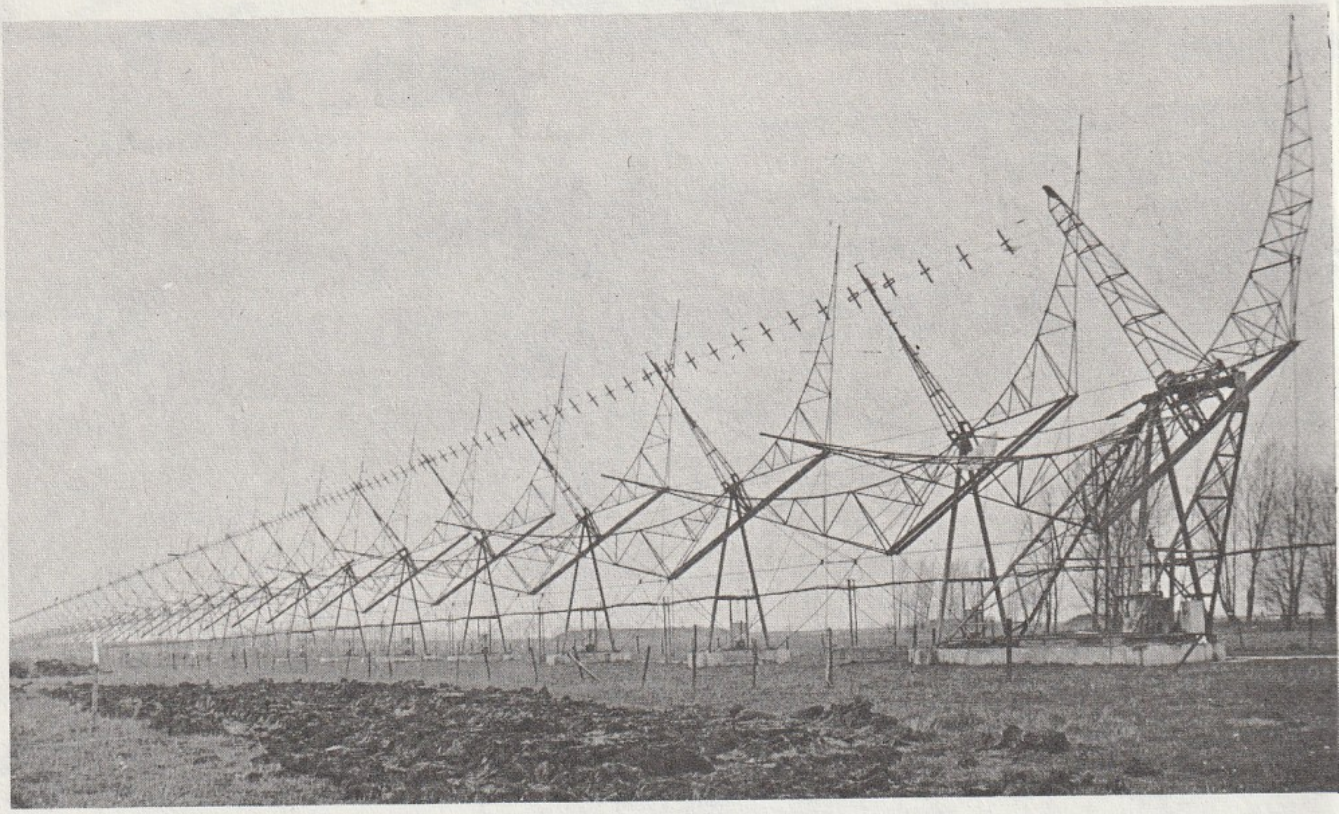
The radio telescopes which make up an interferometer need not be of the same size, and different instruments vary a great deal. How *sensitive* an interferometer is depends upon how big each of its antennas is. An interferometer with two large antennas would be twice as sensitive as a radio telescope with only one large antenna, but an interferometer with one large antenna and one small one—say a quarter the size of the large antenna—would be no more sensitive than the large antenna by itself. However, in both cases, the resolving power is much increased by using two antennas, since two antennas as an interferometer are more than twice as sensitive as each alone.

The 250-foot Jodrell Bank telescope has been used as one part of an interferometer. With it a smaller antenna has been used at a distance of twelve and one-half miles and the resolving power of this interferometer was as good as that of the human eye! A very large interferometer using two "bowl" reflectors, each of eighty-foot diameter, has been constructed in California. In Sydney, Australia, where much pioneering radio astronomy has been carried out, a type of interferometer called the Mills Cross has been developed. This consists of two long lines of dipole antennas and reflectors which form a cross. The lines of antennas and reflectors are 1,500 feet in one instrument and 3,500 feet in another, and these interferometers are equivalent in resolving power to a bowl reflector equal in length to the arms of the cross.

Other interferometers have been designed with one or both of the aerial systems movable. The two eighty-foot bowl reflectors in California are of this kind, while at Cambridge, England, there is a huge interferometer with antennas spaced almost half a mile apart. Of the antennas themselves, one is a long narrow curved reflector of iron wires with a length of almost 500 yards. The other reflector is 190 feet long

(*Following pages*) An aerial view of the Mills Cross interferometer in Australia.





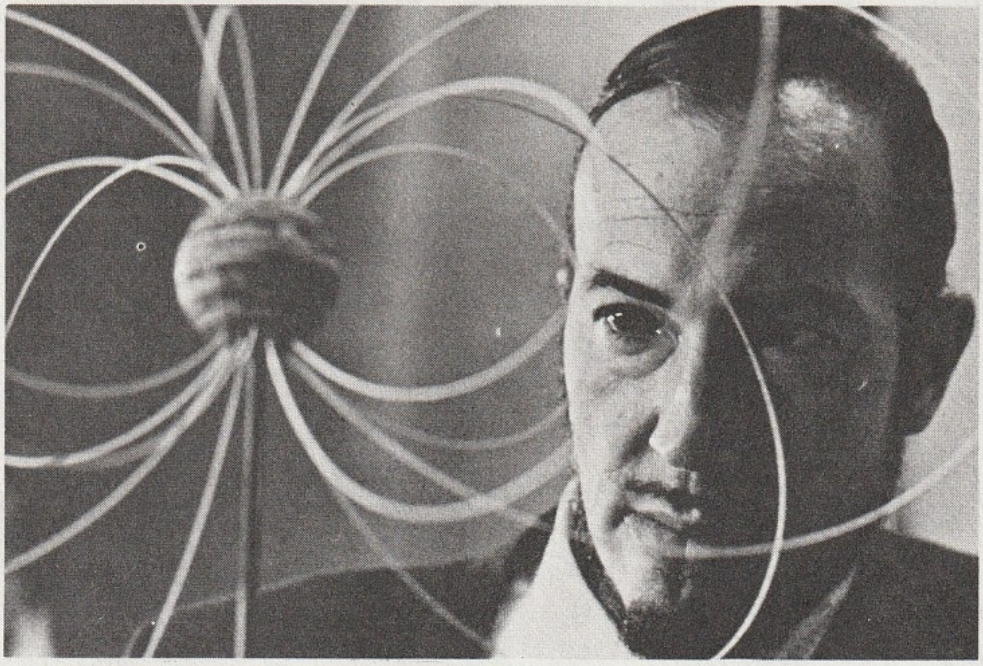
The fixed antenna of the "aperture synthesis interferometer" at the Mullard Radio Observatory in England runs directly east–west and is used to study distant radio sources.

and can be moved in a north-south direction on a type of railroad track more than 300 yards long. These movable antenna interferometers can be used to make observations by the method of "aperture synthesis".

In aperture synthesis observing, studies of the same radio sources are made by two smaller-type antennas, which simulate a single, large paraboloid, the full size being obtained by adding up a series of observations from different positions of the smaller antennas. The recordings give figures which later are fed into a computer which provides the results.

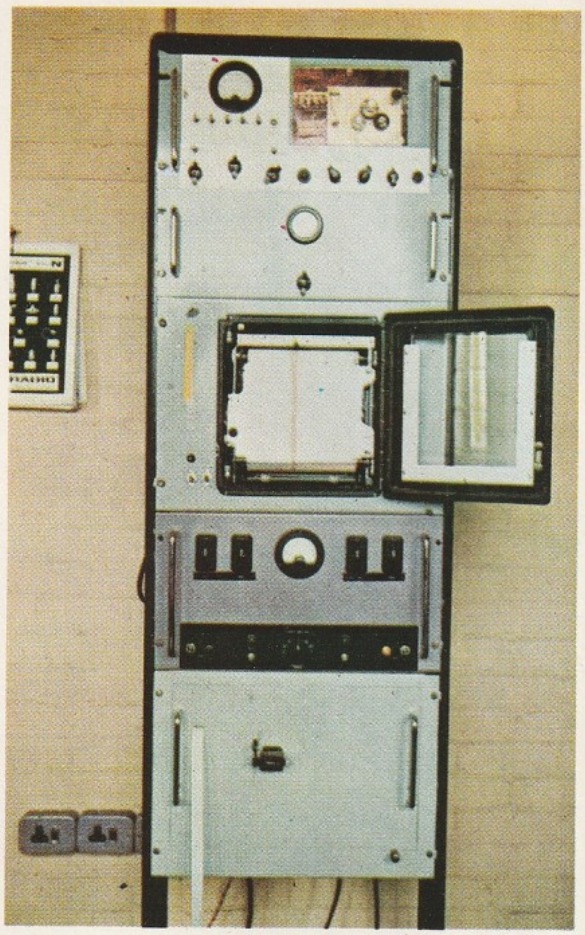
Earthly Interference

RADIO TELESCOPES HAVE TO PICK UP very faint radio waves from celestial objects, and they do this in daytime as well as at night. It is, therefore, very important that radio waves coming from sources on

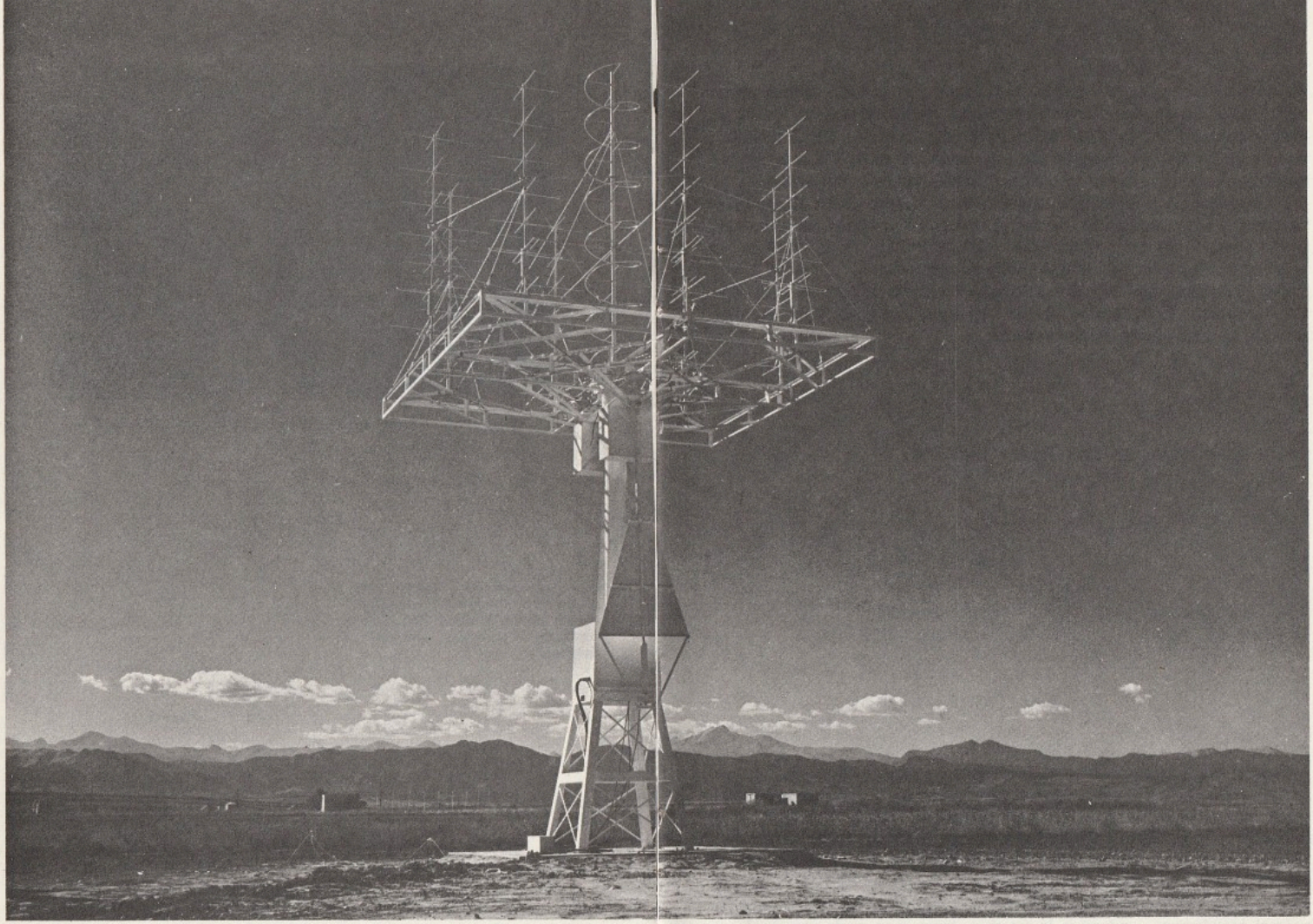


A model of the planet Jupiter illustrates its intense radiation belts.

This is the computer and recorder of the aperture synthesis interferometer at the Mullard Radio Observatory, Cambridge University, England.



2. COMPUTER AND RECORDER



The Ionosphere Explorer telemetry receiver, designed to receive data from Explorer satellites. It is operated by the National Bureau of Standards' Central Radio Propagation Laboratory, Boulder, Colorado.

Science Bulletin

Prepared by SCIENCE SERVICE

OBSERVATORY UNDER COMPUTER CONTROL

Astronomers have long used computers for computation and for such other matters as directing radio telescopes. Now the Massachusetts Institute of Technology claims the world's first completely computer-controlled astronomical observatory. It is the George R. Wallace Observatory located in Westford, Massachusetts, about forty miles from the MIT campus.

All the astronomer has to do is pick a star; the computer does the rest. The astronomer types information about the star he wants into the main computer. The computer searches star catalogues in its memory for the location of the star. It then brings the telescope to bear on the star and instructs a slave computer to track it. Meanwhile the main computer takes data, analyzes it, performs whatever experiments the observer wants and reports back to him.

One of the main reasons for automating an observatory is the current crush on telescope time. There are many more astronomers with observations that they want to make than there is telescope time to accommodate them. As Thomas B. McCord, director of the observatory put it, "So much time must be spent positioning the telescope, adjusting experimental instruments for each observation and recording useless data because the astronomer can't know when he has all he needs. The MIT telescope system reduces or eliminates all these problems, making it possible for astronomers to use a single telescope."

The computerized telescope can also do some things

that conventional ones cannot. It can find invisible infrared objects even in the daytime; it can conduct precise scans of the sky for mapping; and it can quickly reposition itself for a variety of observations.

THE SURFACE ROCKS OF VENUS

The first direct information about the surface rocks of Venus was obtained by the Soviet probe Venera 8, which landed on the planet. It concerns the amounts of the elements uranium, thorium and potassium in the surface, reported by scientists of the Vernadskii Institute of Geochemistry in Moscow.

The data were taken by an instrument that recorded the gamma-ray emissions of these elements. Different kinds of minerals have differing trace amounts of these elements so that measuring their presence is a good way of diagnosing the minerals present. Scooping up samples for direct chemical analysis would require an extension from the Venera that would be difficult if not impossible to accomplish. The gamma-ray measurement was done by an instrument completely protected inside the vehicle.

The results indicate that the Venus surface rocks contain a relatively high amount of uranium, thorium and potassium compared with the basic rock of the earth's crust. According to the level of the content of those natural radioactive elements, the Venus rock is most similar to granites on the earth.

THE 100th PULSAR

The radio observatory at Jodrell Bank, England, announced discovery of pulsar number 100. It is designated PSR 1831-04. This is the thirty-eighth pulsar to the credit of the Jodrell Bank team, making them the world's most prolific discoverers.

The discovery was made during a survey of pulsar positions to see whether they correspond to what would

be expected if they were remnants of supernova explosions. The instrument used by the Jodrell Bank astronomers, the Mark I telescope, happens to be the smallest telescope ever to have seen a pulsar.

JUPITER LEAKS HEAT

The Hale Observatories' 200-inch Hale Telescope at Mt. Palomar has been equipped with a new infrared detector that is ten to 100 times more powerful than previous ones. This has enabled James Westphal, Keith Matthews and Richard Terrile to make sharper pictures of Jupiter than was possible before. In the course of this observation, they found that Jupiter leaks heat from holes and rifts in its clouds.

The Hale observers found localized rifts and holes that enabled them to look deep into the planet's atmosphere and observe the heat coming through.

Color photos taken through the 200-inch telescope were matched with the infrared pictures. Their findings indicate that the heat radiation comes not from the wider orange and red bands, but from the narrow blue and purplish bands, which seems to indicate that those regions are relatively free of clouds. The Great Red Spot on the planet appears as a very cold giant cloud that "probably sticks up above the rest of the clouds."

FROM DUST TO PLANETESIMALS

Astronomers think they understand how the cooling gas in the early solar nebula condensed to form dust grains and later how the larger planets were formed from collisions of objects several miles in diameter (planetesimals). But how the planetesimals themselves formed from the dust has been a puzzle.

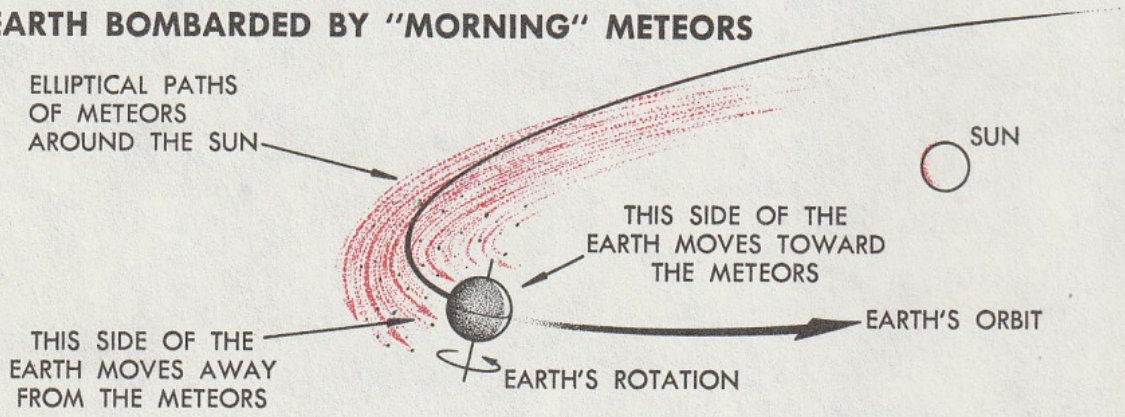
Now Peter Goldreich and William R. Ward of the California Institute of Technology think they have the answer. They propose that the planetesimals were formed from gravitational collapse.

This is what they believe happened: The original solid particles condensing from the gas formed a thin, platelike disk of debris orbiting the sun. Then the combined gravitational attraction of countless numbers of these grains broke up the disk to form separate clusters. Each cluster was composed of bits of debris all attracting one another. As the space between the grains continued to shrink, portions of the cluster collapsed in on themselves to form larger objects. These would form planetesimals about a half mile in diameter. "It took only one to ten years to produce bodies of this size," said Goldreich.

Clusters containing 10,000 of these larger bodies continued to rotate around themselves in a delicately balanced equilibrium, prevented from contracting to form one object by the strength of their rotational patterns. As the planetesimals interacted with the hydrogen gas in the nebula, however, they slowed and began to contract upon themselves. It would take several thousand years to form the larger planetesimals five miles in diameter from the one-half-mile-diameter bodies. Once this large, the planetesimals could then grow by direct encounter with debris into planets.

the earth are completely avoided. Radio waves from earth sources cause what the radio engineer calls "interference". This is due to sparks of electric motors and cars, on electric railways and streetcars. It is not practicable to stop railway and streetcar sparking and so it is clear that no radio telescope can be set up in a city. Moreover, the farther away a radio telescope is built from main roads and from domestic and agricultural electric appliances, the better will be observing conditions. This is the reason why most radio telescopes are built in what seem to be isolated places. Even so, it is sometimes necessary, as it was in Cambridge, England, for astronomers from the radio observatory to visit the few people living nearby and put specially designed spark suppressors on all their electrical equipment.

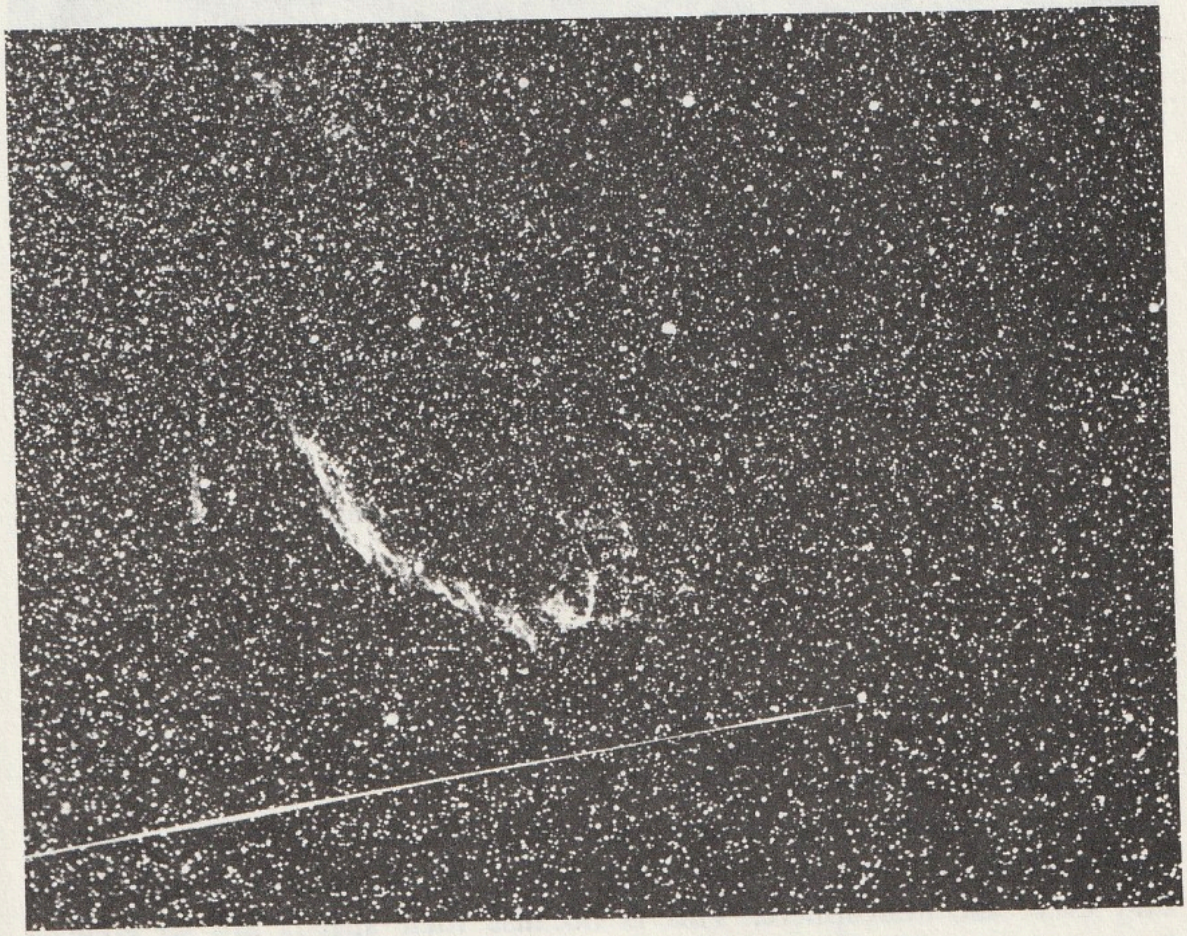
EARTH BOMBARDED BY "MORNING" METEORS



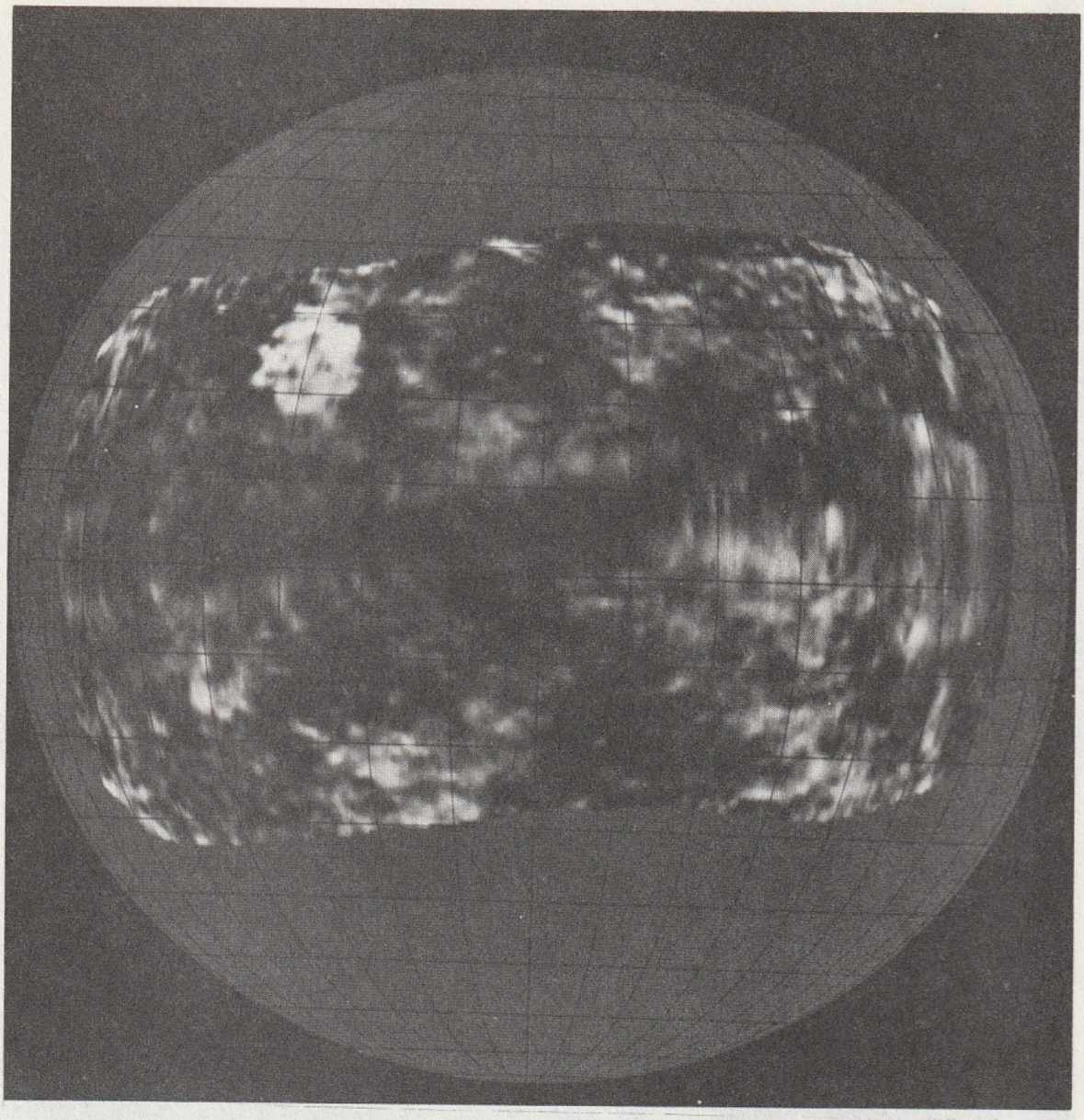
Natural interference, due to the fact that we observe from the surface of the earth, has also to be taken into account by radio astronomers when they are examining the recordings made by their telescopes. This interference is partly due to the electrified particles in the upper air and now and again in great bursts by the sun, and also due to the clouds of electrified air particles in the ionosphere mentioned earlier. The site chosen for a radio observatory does not seem to have any effect on such natural interference, and so it is freedom from man-made electrical interference which is the main consideration.

Radar and Meteors

RADAR IS THE NAME given to the method of sending out pulses of radio waves and receiving back these pulses after they have been reflected by a distant body. Radar works on very short wavelengths—five meters and even less—and a very directional antenna is required. A radio telescope bowl reflector with a dipole antenna meets this requirement and the 250-foot Jodrell Bank instrument has been used in this way. In addition to a directional antenna, radar equipment needs a radio transmitter which can send out pulses of radio waves at very great strength, a radio receiver and some means of coding the radio pulses sent out so that it is possible to find the time taken between the sending



The N16 Nebula NGC 69924 and a meteor trail.



Radar astronomers plotted this map covering some 30 million square miles of Venus' surface. It was made using radar beams from a tracking station in California.

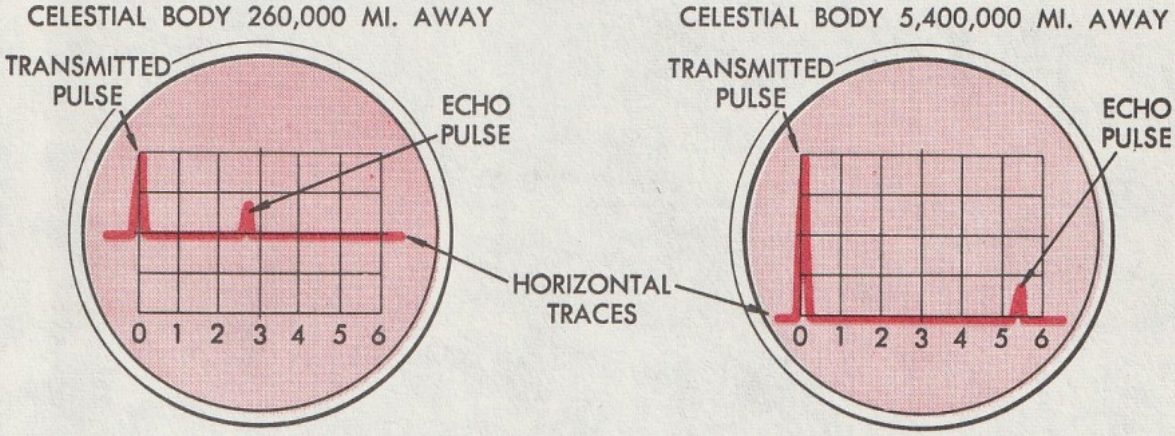
out of a pulse and its return. Radar equipment was developed in Britain and the United States during World War II, and was put into civilian use as soon as the war had ended.

The first scientific use of radar was to study *meteors*. These lumps of rock and metal from interplanetary space are sometimes visible when they enter the atmosphere. This is because their speeds are so great—between seven and forty-five miles a second—that the friction caused as

they rush through the atmosphere heats and vaporizes them. Most meteors have "burned out" at a height of about forty miles above the ground, but very large lumps, which are rare, do not become completely destroyed. These land and can cause wide areas of destruction, evidence of which can be seen, for example, in the great meteor crater in Arizona.

Most meteors burn out in the atmosphere. Some are visible at night as a streak of light among the stars, lasting for only a second or less. Such meteors as these can be photographed, the bright trails they leave being seen against the background of stars. Yet most of the meteors are either too dim to be photographed or arrive in daylight and cannot be seen at all, and it is here that radar astronomy has a special task to do. Much of the work has been carried out in England and the discoveries made have been surprising.

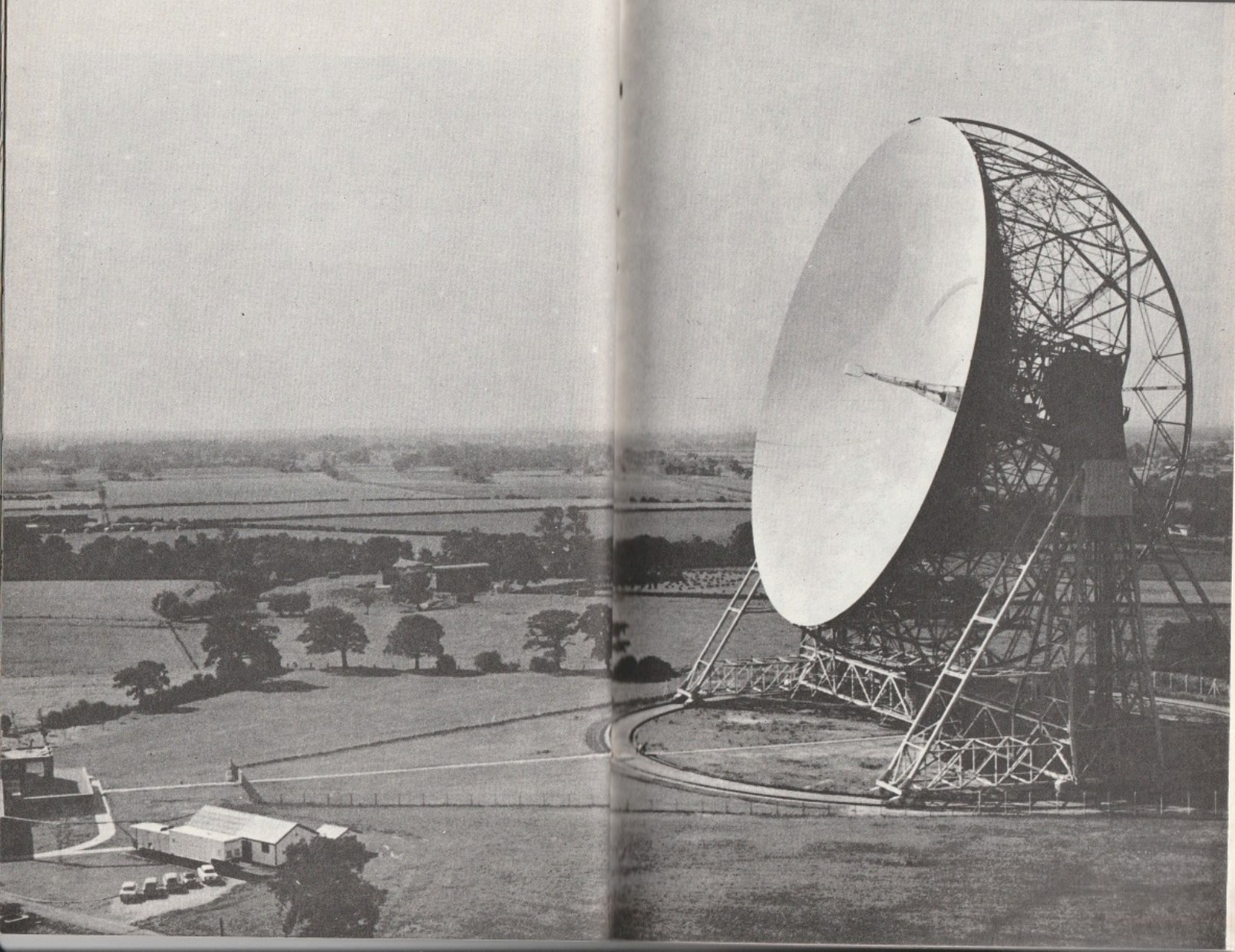
TWO DISPLAYS OF DISTANCE IN RADAR ASTRONOMY

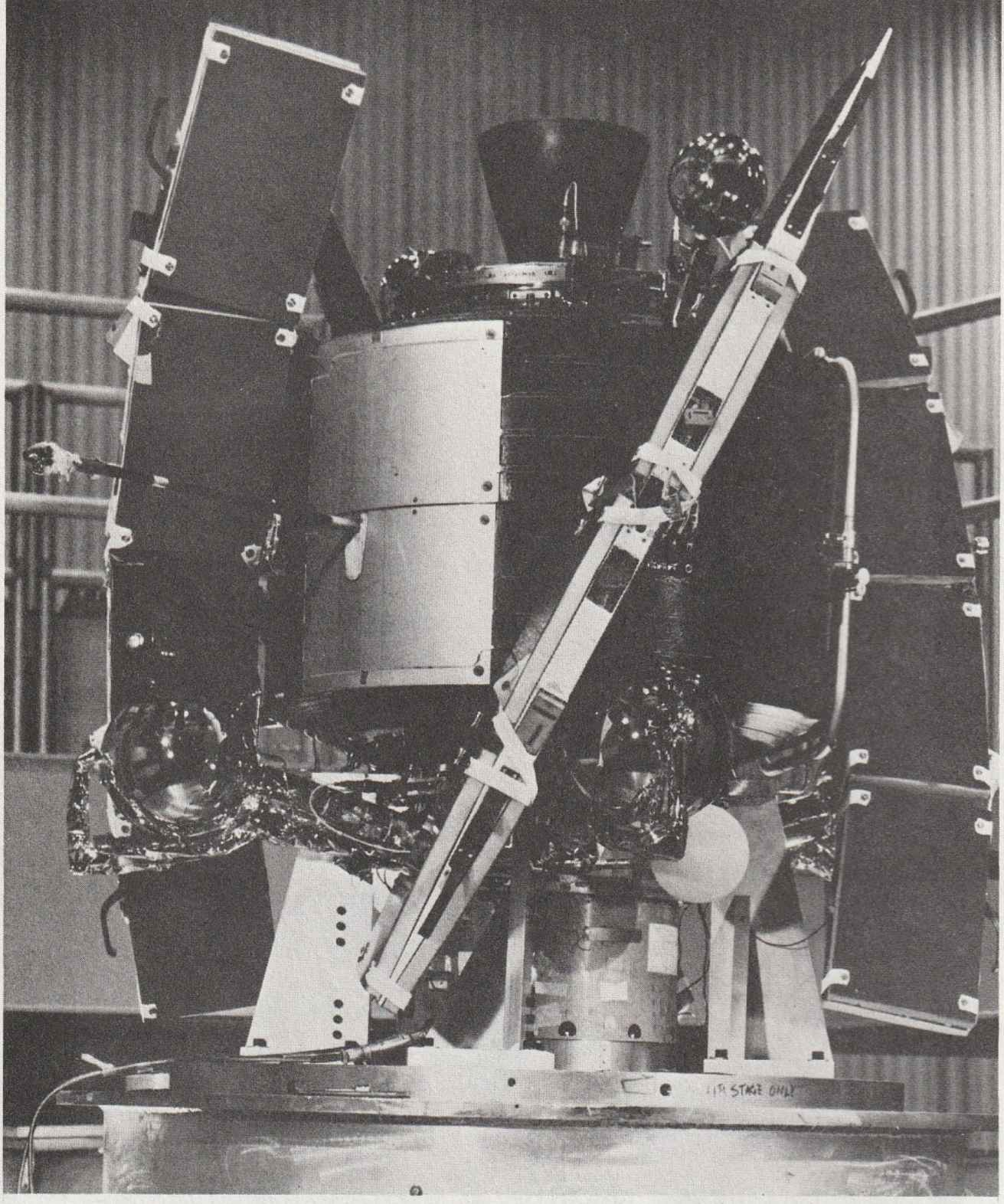


Screen of cathode ray tube *above* shows a pulse transmitted with medium strength for a comparatively short distance. Echo returns weaker and to the *right* along the horizontal scale calibrated in increments of 100,000 miles.

Here the cathode ray tube is adjusted for a stronger transmitted pulse for measuring a greater distance. The very much weaker echo returns further to the *right* along the horizontal scale calibrated in increments of 1,000,000 miles.

(*Following pages*) An aerial view of the Jodrell Bank radio telescope in England.



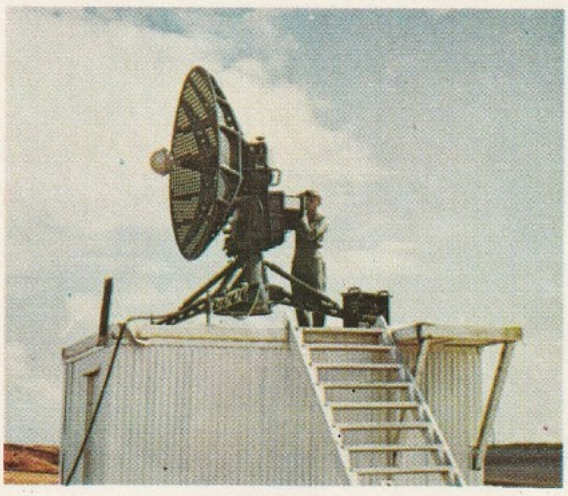


Radio astronomy satellites are a relatively new tool. This one studied low frequency radio signals from the Milky Way while orbiting the moon.

Echoes from the Moon

RADAR AND COMPUTERS, working in tandem, are now starting to map the planets in our solar system. The moon was the initial target, being the most accessible to radar's limited sensitivity. These "radar

Radar was developed during World War II and used to locate and track enemy planes. Potential uses in the fields of science were obvious and at war's end radar units were turned on objects in space.

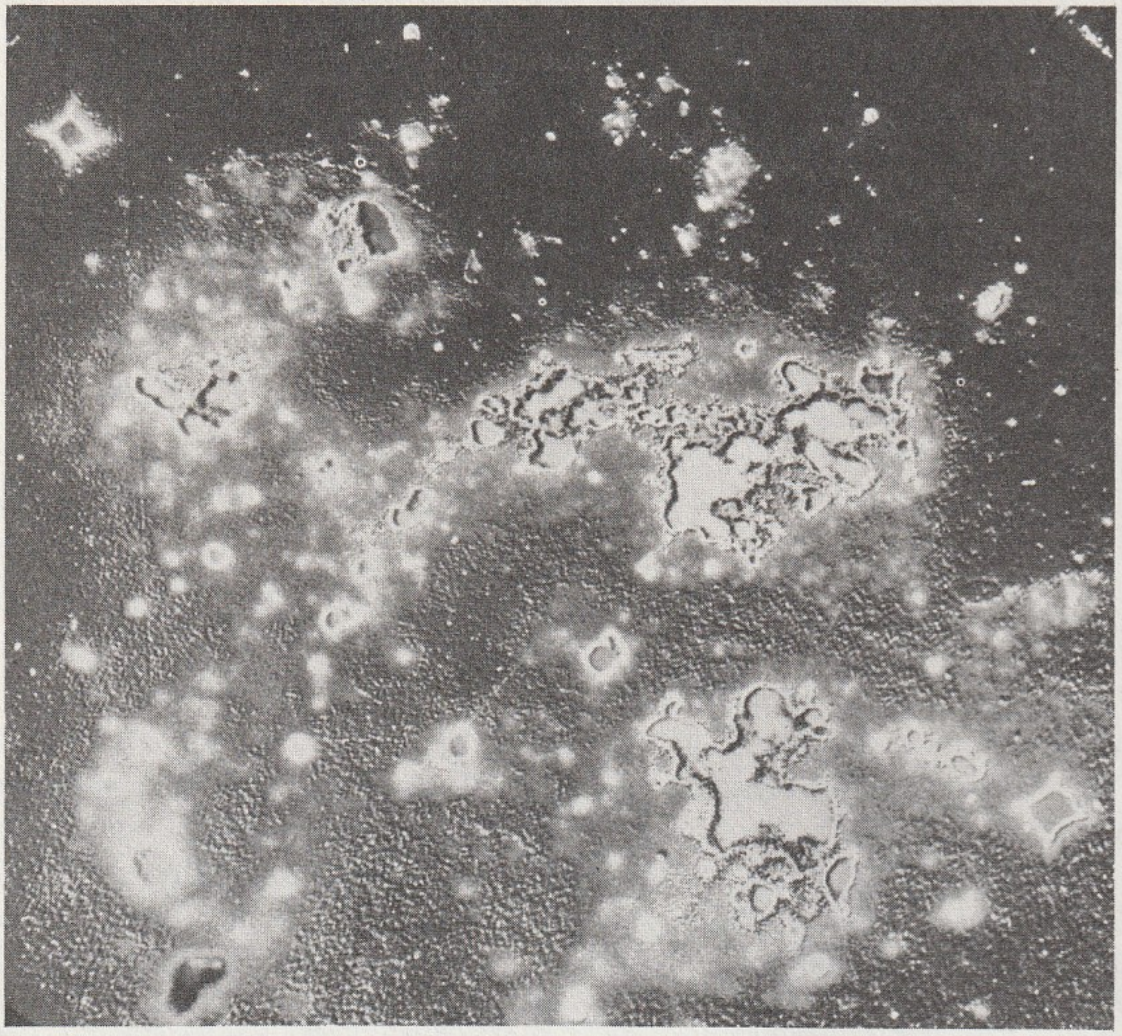


8. MILITARY RADAR

maps" resemble photographs that might be taken through a telescope. The radar beams tell the story of the moon's surface by the way they bounce off various kinds of terrain. Cornell University scientists have used the radar capacity of the 1,000-foot radio telescope at Arecibo in Puerto Rico to make a rough surface map of Venus. In addition, these radar echoes from space have enabled us to measure the moon's distance with great accuracy. This has been achieved by timing very carefully the interval taken for a radar pulse to go to the moon and back. The result is that the moon's distance has been measured to within half a mile—an answer which means an error in checking the pulses of certainly no more than five-millionths of a second!

The strength of an echo received from a radar pulse depends not only on the strength of the pulse sent out, but also on the size and distance of the object reflecting the pulse. The moon is only a quarter of a million miles away from us, but Venus, the nearest planet, never comes closer than 25 million miles, and the result is that, to get radar echoes from Venus, we need 5 million times more power than we do for lunar echoes. To get echoes from Mars, which is smaller than Venus and farther away, the power needed is nearly twenty times more.

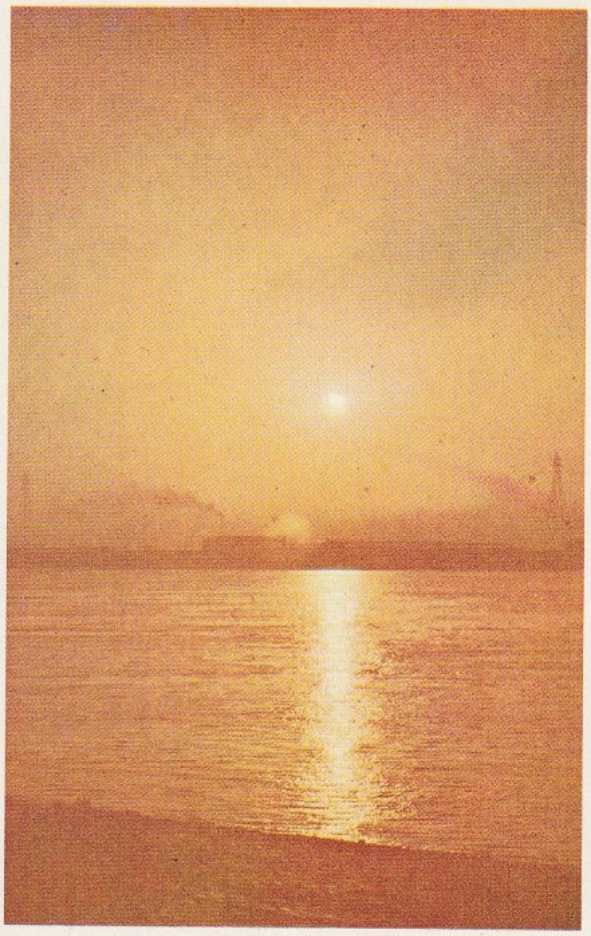
Jodrell Bank and the Lincoln Laboratory at Westford, Massachusetts, as well as the Jet Propulsion Laboratory at Pasadena, California, have all sent radar pulses to Venus. By timing the echoes carefully, it has been possible to determine by radar the distance from earth to Venus,



This photograph of the Large Magellanic Cloud, a nearby galaxy visible only from the southern latitudes on earth, was one of many made by Apollo 16.

with the first results from Lincoln Laboratory giving an accuracy equal to the optical methods previously used by astronomers. A number of stations have bounced signals off Mars, Mercury and the sun, as well. The long-distance radar record, established by Russia, involved a beam sent to Jupiter and back. Jupiter, at certain times, is more than a billion-mile round trip from earth.

The modernization of the famous Arecibo Observatory in Puerto Rico—with its 1,000-foot-wide radio antenna—increased the telescope's sensitivity 100-fold for radio work and ten times that for radar, thus decreasing the minimum wavelength observable from fifty centimeters down to about seven centimeters. These modifications can give astronomers at Arecibo clearly defined pictures of Venus that will show surface features about a



The leading edge of the moon has just bitten into the sun's disk, or photosphere, at the beginning of this partial solar eclipse.

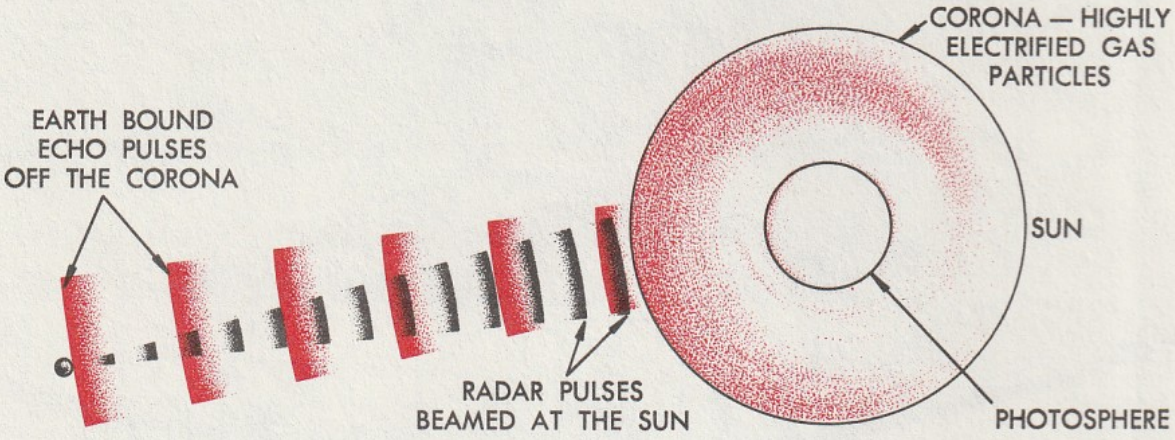
10. PARTIAL SOLAR ECLIPSE

mile across. Later Mercury may be mapped, but it is not expected that the maps will be as detailed as those of Venus because Mercury is farther away.

Radar astronomy of the planets amounts to active probing of other worlds. It is like swinging a searchlight around on a dark night. The challenge of getting precise results is full of difficulties, but gradually these are being overcome. It is certain that radar studies of all the planets, especially Venus, will be very important and an increasing number of telescopes around the world are being used in this work.

Earth-bound observations of the sun have given scientists much data about that star—the source of all life on earth. But until America's Skylab missions, with its Apollo telescopes in space, man saw only the calm flat disk known as the "photosphere", which is what we see from earth. Over the sun's disk lies a very thin atmosphere of gas called the "corona", which extends for millions of miles. The light of the corona is fairly dim—

STUDYING CORONA BY RADAR


CORONA — HIGHLY ELECTRIFIED GAS PARTICLES
EARTH BOUND ECHO PULSES OFF THE CORONA
SUN
RADAR PULSES BEAMED AT THE SUN
PHOTOSPHERE

it is only about half that of the full moon, and the corona cannot normally be seen at all because of the glaring brightness of the sun's disk. The only times it is visible from the surface of the earth are when observations are made from a mountain observatory using an instrument called a "coronagraph", or during the few minutes of a total solar eclipse, when the moon completely blots out the light of the photosphere.

The corona is very highly electrified and should act as a reflector to radar pulses. The successful reception of radar reflections back from the corona by a group at Stanford University in California allows astronomers not only to make radar measures of the sun's distance from the earth, but also to do more. By carefully examining the exact form of the reflections and measuring exactly their wavelength, it is possible to learn much about the corona itself and so add to our knowledge of a not-very-well-understood part of the sun.

Radio Waves from Space

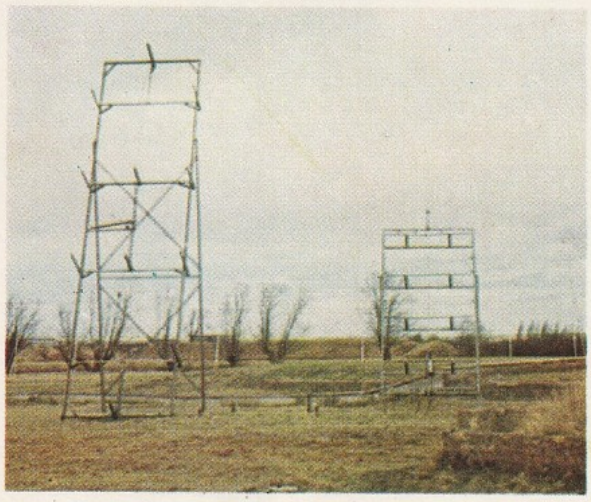
RADAR PULSES CAN BE USED ONLY for studying objects relatively near to us in space. The power required makes it impossible to consider using radar as a means for studying the stars and, moreover, the

distances to the stars are so great that, except for those nearby, we would have to wait hundreds of years for the echo to be returned. For these reasons radio astronomy must be concerned mainly with the radio waves that are being emitted by celestial bodies.

Radio astronomers recognize two kinds of radio waves—those they call "thermal" and "non-thermal" radiation. Thermal radiation, as its name implies, is radiation that comes from a hot body, and the wavelengths of this radiation depend upon how hot the body is. This can be seen if we heat something like a piece of iron; as the iron becomes hot it begins to glow with a dull red glow, but as its heat grows, so the wavelength of its radiation changes, first to a straw hue, then to yellow and finally, almost to white.

The sun is a hot body and sends out thermal radiation. Most of this radiation we see as light and feel as heat, but some of it is in the form of very short radio waves. The corona, however, sends out much radio radiation, but in longer wavelengths than does the rest of the sun. The Milky Way, which we can see as a hazy band of light across the sky, also sends out thermal radiation because it contains hot gas.

Non-thermal radiation can be likened to the radio waves sent out by radio and television stations. The transmitting antennas of these stations do not get hot, yet great quantities of radio waves are sent out, because the energy used by the stations is turned almost entirely into radio waves. A similar thing happens with certain celestial bodies which turn much



6. SOLAR ANTENNAS

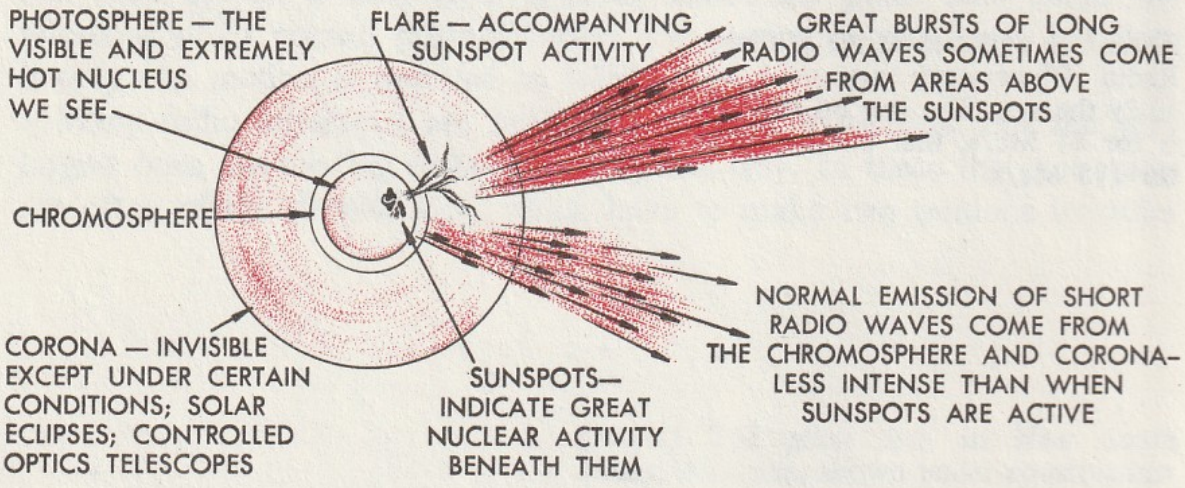
These two antennas at the Mullard Radio Observatory are used to study the sun. The one on the left is for 81 Mc/s, that on the right for 175 Mc/s.

of their energy directly into radio waves. This type of radiation comes, quite frequently, from high in the solar corona, caused by disturbances inside the sun. All the dark gaseous parts of the Milky Way send out radiation of the non-thermal kind. Radio telescopes receive both thermal and non-thermal radiation from space.

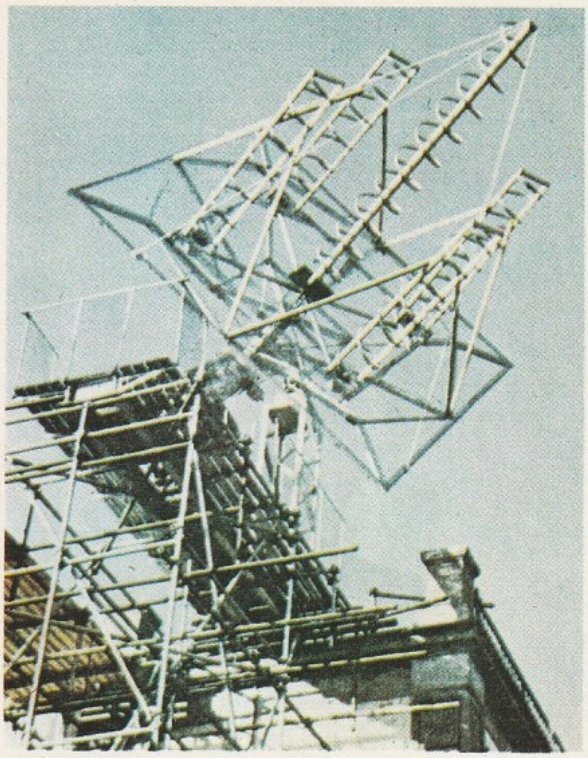
The sun is a star and, as has been noted, is by far the nearest star to us in space. The next nearest, which lies in the constellation of the Centaur, is 300,000 times farther away. The sun is just like the myriads of other stars we can see in the sky, even though some of them are brighter and larger bodies, and some are smaller and dimmer. All stars, including the sun, generate their radiation in a similar way, and therefore studying the sun can tell us much about the stars in general.

What we see when we photograph the sun is a huge glowing ball of gas. Underneath this hot and extremely bright photosphere lies other gas, while in the central parts of the sun atoms are continually being broken down and built up. In the center of the sun it is just as if hundreds of thousands of hydrogen bombs were continually exploding. The results of this reach the photosphere. This is why the photosphere shines so brightly and sends out X rays and ultraviolet light. Yet sometimes dark spots appear on the photosphere and these "sunspots" are evidence of greatly increased activity below. When sunspots appear, great bursts of the longer radio waves are often received. These are a thousand times more intense than those which radio astronomers normally receive and which come from what is called the "quiet" sun, being radiated by the corona and the "chromosphere", that layer of not very bright gas which lies just above the photosphere. These immense bursts of radio waves

SIGNALS FROM THE SUN


PHOTOSPHERE — THE VISIBLE AND EXTREMELY HOT NUCLEUS WE SEE
FLARE — ACCOMPANYING SUNSPOT ACTIVITY
GREAT BURSTS OF LONG RADIO WAVES SOMETIMES COME FROM AREAS ABOVE THE SUNSPOTS
CHROMOSPHERE
NORMAL EMISSION OF SHORT RADIO WAVES COME FROM THE CHROMOSPHERE AND CORONA— LESS INTENSE THAN WHEN SUNSPOTS ARE ACTIVE
CORONA — INVISIBLE EXCEPT UNDER CERTAIN CONDITIONS; SOLAR ECLIPSES; CONTROLLED OPTICS TELESCOPES
SUNSPOTS— INDICATE GREAT NUCLEAR ACTIVITY BENEATH THEM

Photograph at right shows the steerable solar antenna at the Arcetri Observatory in Florence, Italy.

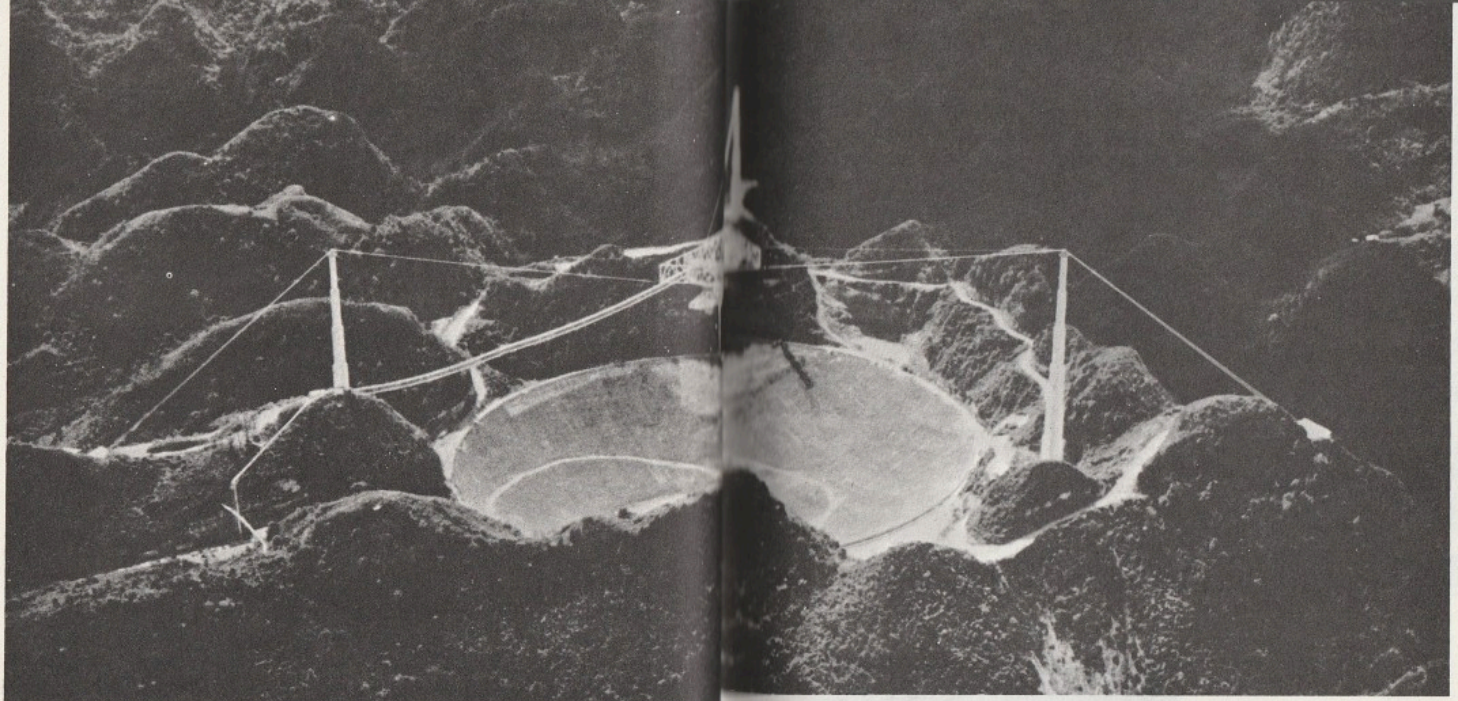


7. SOLAR ANTENNA

are usually accompanied by an intensely bright area or "flare" near a sunspot, and it is clear that they are caused by a sudden burst of thermal radiation from below the photosphere. The visible flare and the burst of radio waves also are accompanied by a burst of X rays, ultraviolet rays and atomic particles.

When there are sunspots but no flares accompanying them, the radio waves emitted by the quiet sun do not remain constant but begin to fluctuate, and the radio signals gradually become stronger. These changes do not correlate with changes in the number of sunspots, although it has been found that the radio waves seem to be generated in the sun's atmosphere *above* the sunspots and not in the sunspots themselves. The changes in radio waves do, however, correlate with the calcium areas of the sun's spectrum.

Radio astronomy has helped considerably to increase our knowledge of the corona. Being visually very dim, the corona is hard to observe by optical means, even during total eclipses. During some eclipses it has been traced quite a long way from the sun but was believed to extend



Aerial view of the Cornell University 1,000-foot stationary bowl at Arecibo, Puerto Rico. A dirt road may be seen running beneath the iron mesh of the largest stationary dish telescope in the world.

no more than about 2 million miles, at the most, above the photosphere. Direct radiation of radio waves from the corona has been received during daylight up to about 1½ million miles. However, by examining a distant radio source as the sun passes in front of it, it is possible to discover how far the corona extends by observing how the radio waves from the distant source are affected. It was in this way that Professors M. Ryle and A. Hewish at Cambridge University, England, found that the corona could be traced out to more than 6 million miles, and in the line of the sun's equator to 12 million miles or more. It has even been suggested that the corona extends as far as the earth itself.

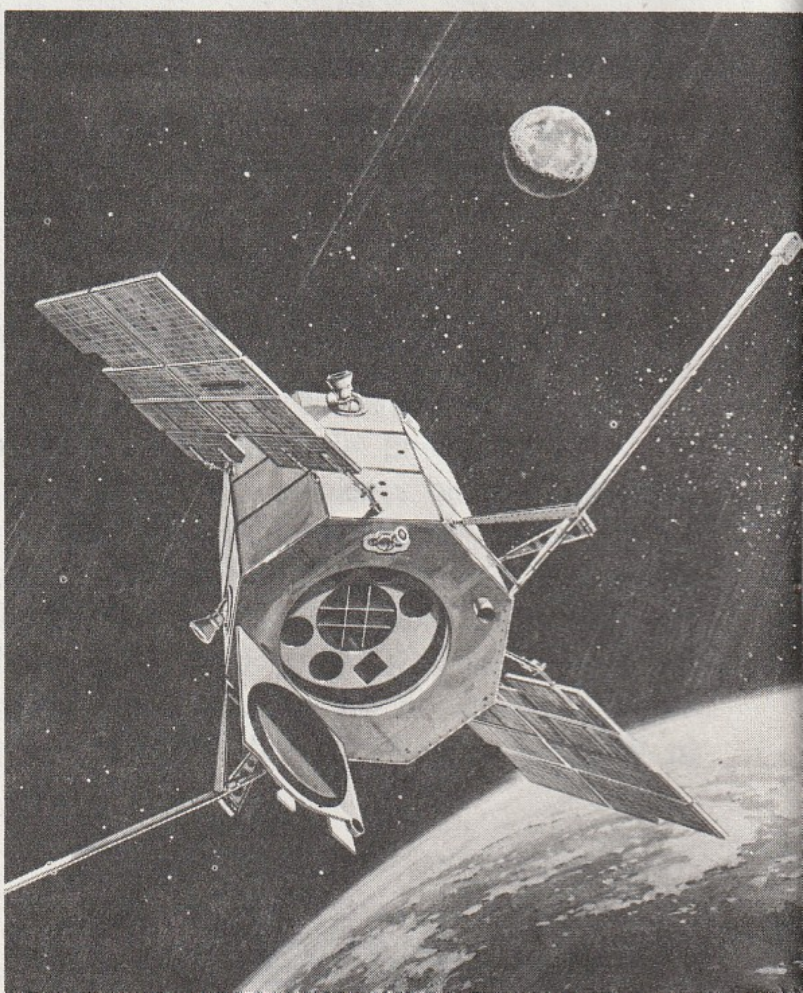
Radio Waves from the Planets

ALL THE PLANETS of the solar system receive light and heat from the sun, and all emit thermal radiation. This radiation is very weak and special receivers have been designed for radio astronomy observations of the planets. One of these receivers—the MASER, developed at Columbia University—was mentioned earlier, but the other, the "travelling wave tube", was developed before World War II and improved during it. Both have been used with success. Some early, valuable results on the planets Venus, Mars and Jupiter were obtained in Washington in 1956 and 1957, but improvements in these receivers

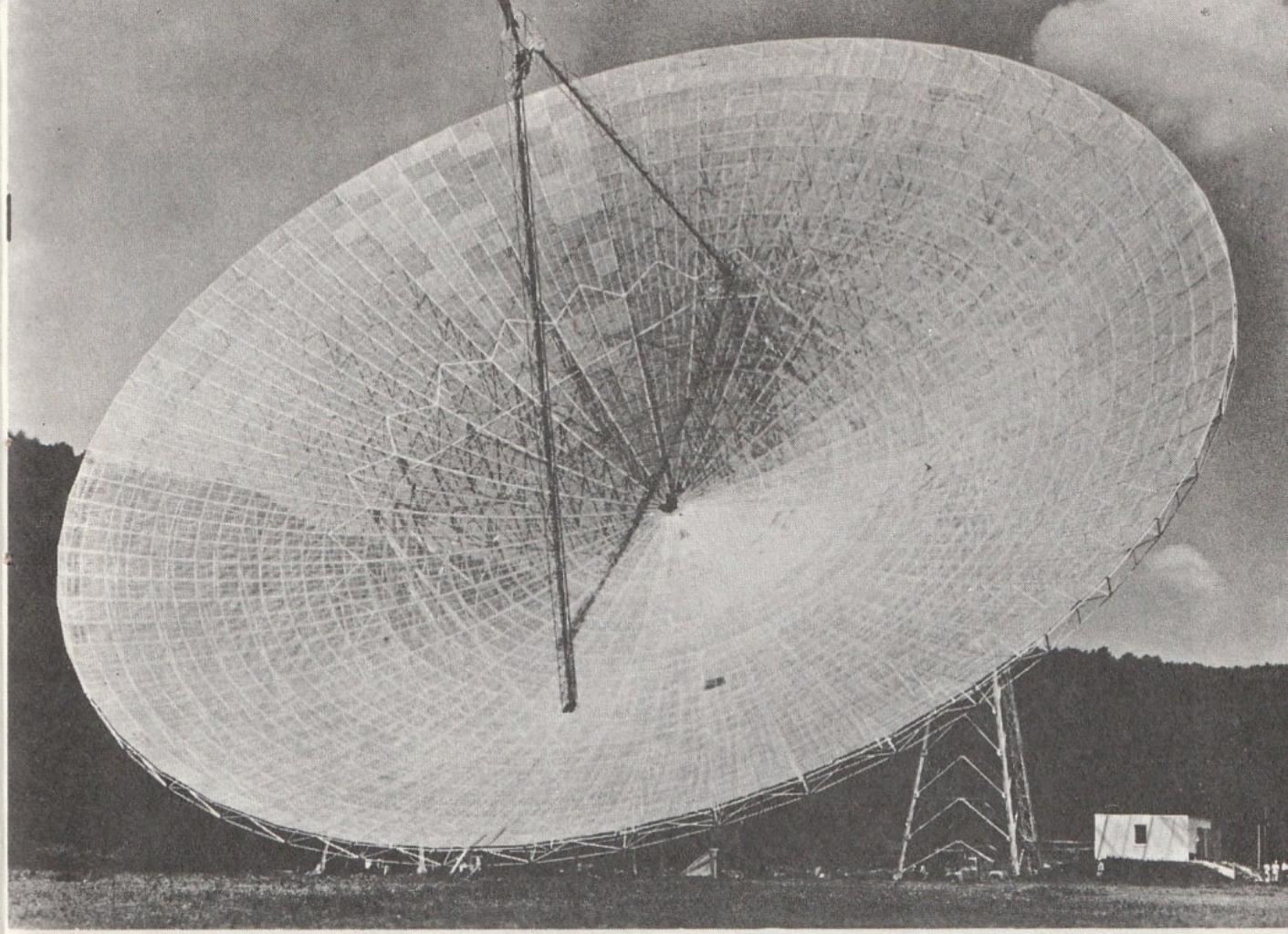
have allowed later work to be more accurate and also to be extended.

The radio-wave measurements are mainly concerned with finding the temperature of the surfaces of the planets. Measurements of the surface temperatures of planets can be made visually using infrared rays, but these measurements are very difficult to make. Infrared rays have some penetrating power, but in most cases short radio waves of about three centimeters are even better.

An exception to this was learned from Mariner 10 data gathered by six non-imaging experiments on its swing past Venus en route to Mercury. Radio waves cannot penetrate the dense Venusian atmosphere below an altitude of thirty miles. Venus, nevertheless, is an intense source of radio emissions and at the three centimeter wavelength it gives off as much radiation as if it were a hot body. Radiometers on Mariner 10, which got a thousand times closer to Venus than earth instruments had ever observed, recorded an average surface temperature of 800° F., high enough to melt lead and zinc.



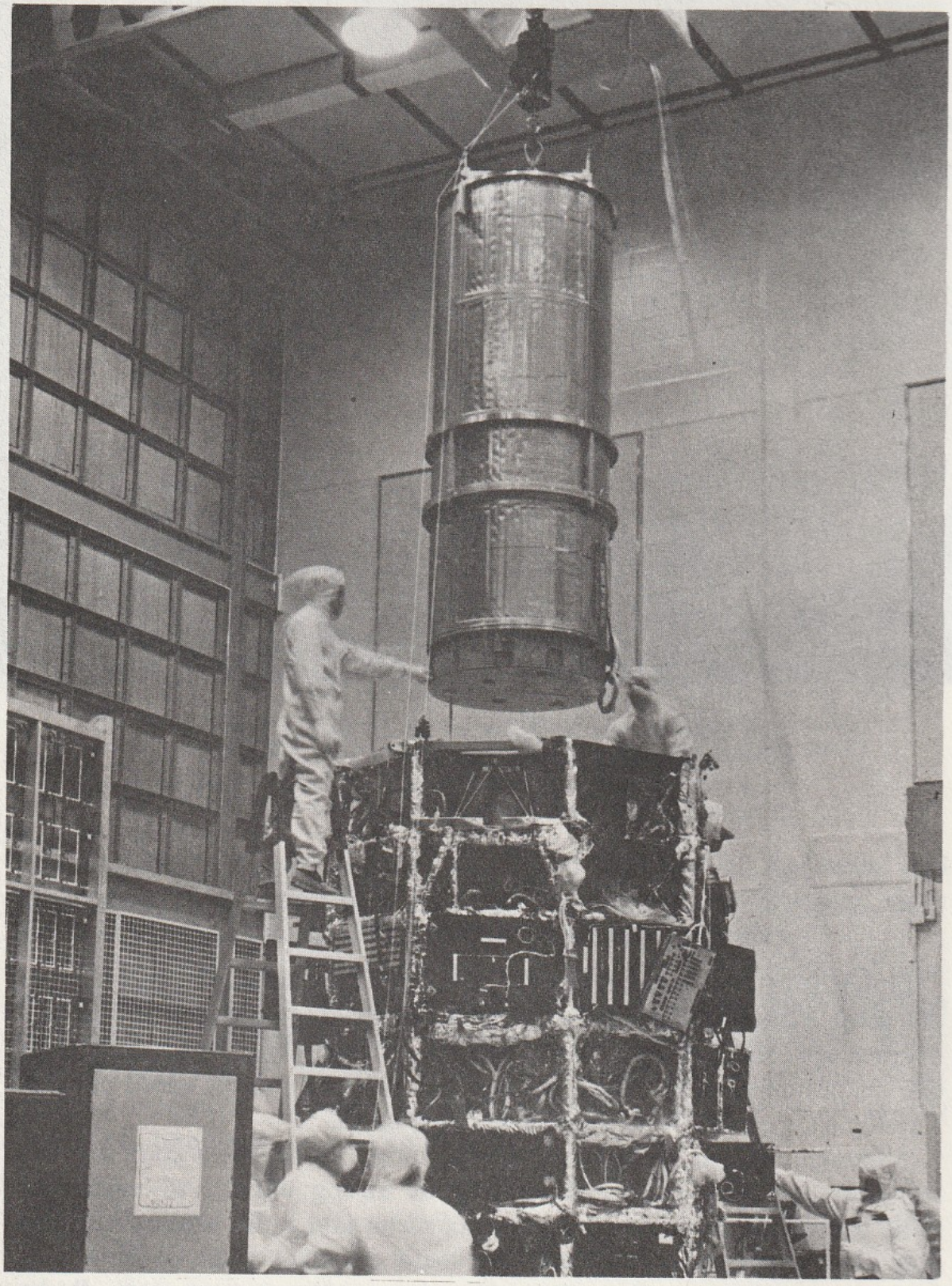
Artist's concept of a 4,400-pound Orbiting Astronomical Observatory designed to study hot young stars in the invisible ultraviolet spectrum.



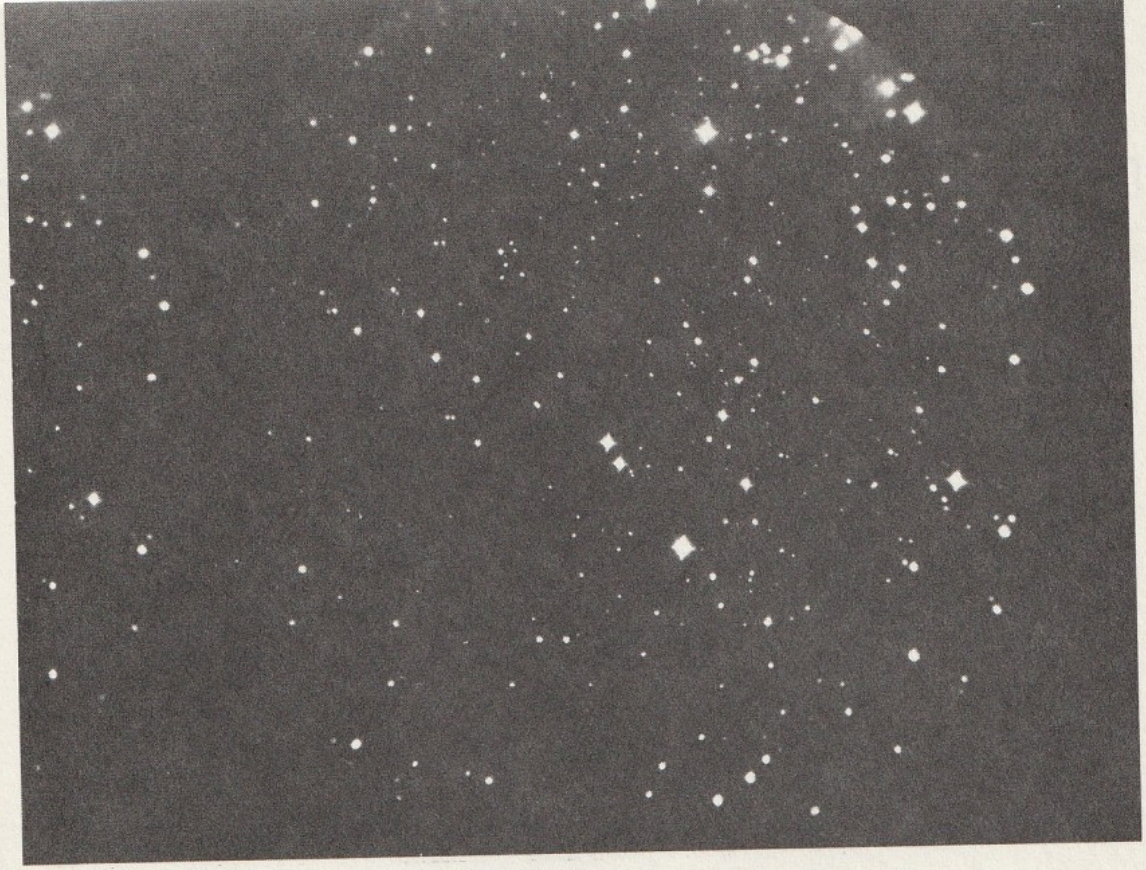
This 300-foot radio telescope of the National Radio Astronomy Observatory at Green Bank, West Virginia, is the world's largest movable telescope. It stands twenty-three stories high, and was built at a cost of $850,000.

Jupiter is of considerable interest to radio astronomers because it sends out great bursts of radio waves. These signals from Pioneer 10, an unmanned spacecraft which probed Jupiter, reached earth with a power of one-quadrillionth watt, travelling like all radio signals at the speed of light. The signals took forty-five minutes to reach earth.

Although the sun emits radio waves, most of the other stars are too far away for their radio radiation to be strong enough to affect our radio telescopes. However, this does not mean that radio astronomers can only observe the sun and planets, for there are many radio sources lying farther away from us than the sun and even the nearest stars. Radio astronomers sometimes refer to these as "radio stars", although none of them is a simple star and most are not even stars at all.



Technicians lower a telescope into the Orbiting Astronomical Observatory spacecraft which studied ultraviolet light in space.

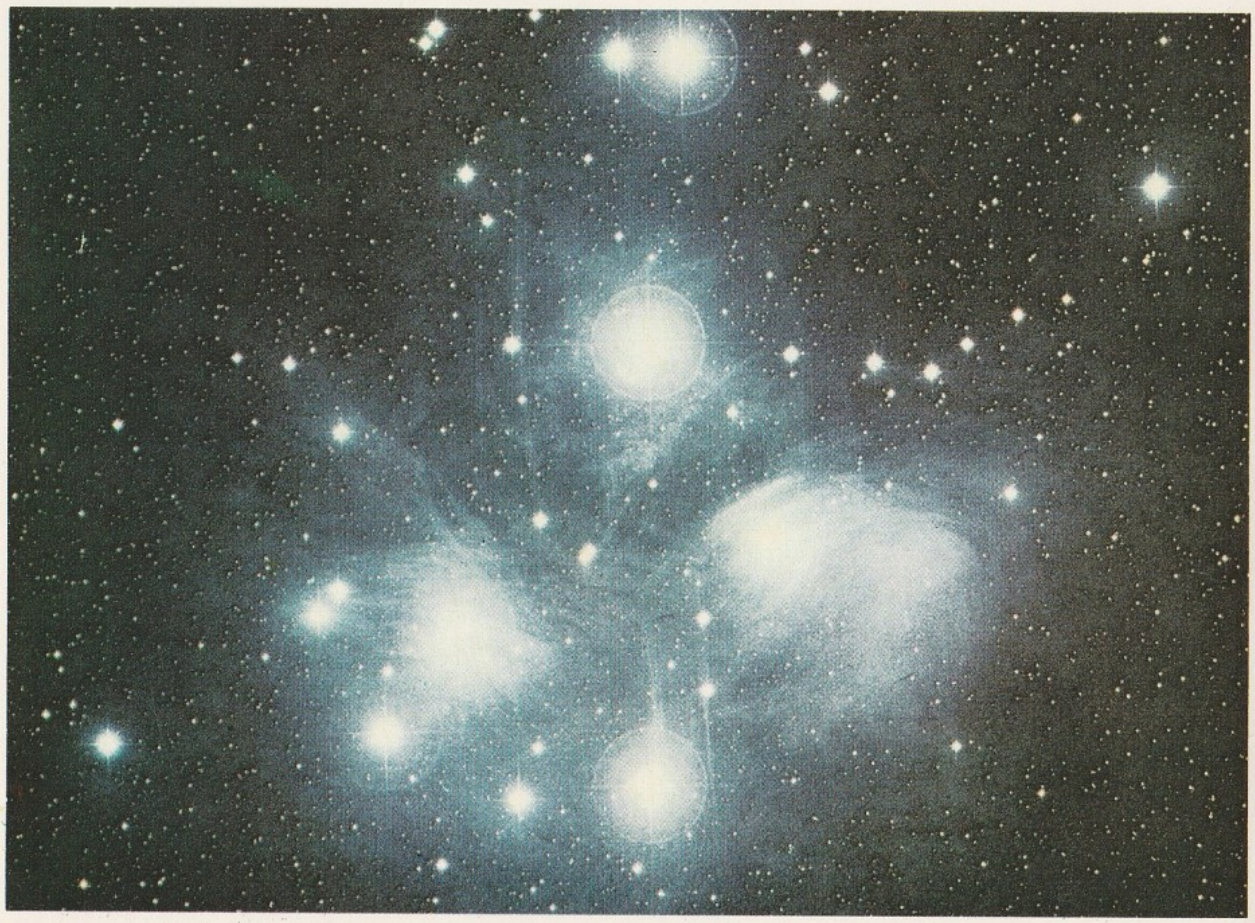


The North America Nebula is faintly visible in the upper right-hand corner of this far-ultraviolet study.

One of these very bright radio sources is known as the Crab Nebula. This is really the remains of a stellar explosion which happened in 1054. At the present time the star is of no special brightness, but the explosion caused a huge shell of gas to be shot into space, and it is this gas shell which is sending out radio waves. The shell also emits light so that both optical astronomers and radio astronomers can study the object, which is called a "supernova". It has been found that the radio waves are caused by high-speed electrically negative atomic particles (electrons) of the gas moving in an area which is like a huge magnet. Other supernovae sources have been found and examined with radio telescopes.

Many of the stars we can see when we look up at the night sky are part of one huge island of stars, interstellar dust and gas. This is the Milky Way galaxy, which astronomers call "the Galaxy", and it is shaped rather like a couple of large saucers, one over the other, so that there is a bulge in the center. Some of the gas in the Galaxy can be seen in optical telescopes as large bright patches that glow because of the light and other energy given to the gas by nearby hot stars.

Most of the gas in the Galaxy is hydrogen and much of it gives out no light. However, this cold gas does emit non-thermal radio radiation on a wavelength of twenty-one centimeters and this means that radio as-

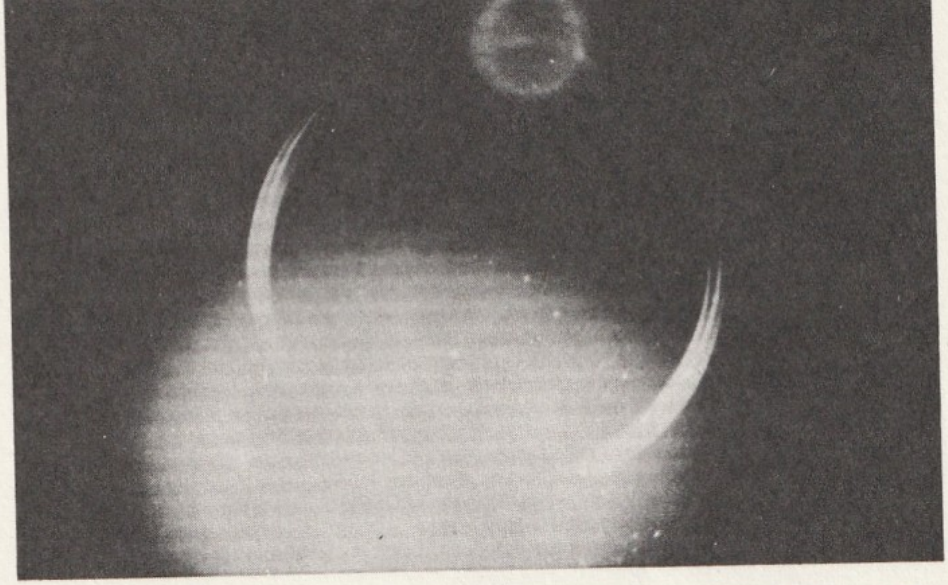


9. THE PLEIADES IN TAURUS

This astonishing photograph, made with the forty-eight-inch Schmidt telescope at the Mt. Palomar Observatory shows the Pleiades and nebulosity in Taurus.

tronomers are able to observe it. Optical astronomers have been unable to observe very far towards the center of the Galaxy—that is, in the direction of Sagittarius—because of interstellar dust. Fortunately, the twenty-one-centimeter radio waves penetrate the dust, and radio astronomers have been able to build up a much more complete idea of what the whole Galaxy is like.

It has been found that the Galaxy is constructed rather like a giant pinwheel with a dense, bright center and trailing spiral arms, and also that the solar system and the sun lie near the outside in one of the spiral arms. These discoveries have shown clearly the importance of radio astronomy, because optical astronomers could not obtain enough informa-



This solar eclipse—where the sun passes directly behind the earth and forms a halo of light around the earth—was photographed by the Apollo 12 astronauts in 1969 as they sped home on their way from the moon.

11. THE CRAB NEBULA

The Crab Nebula in Taurus is a cloud of very hot gas. It is expanding from a central point—the result of a stellar explosion.

12. THE GREAT GALAXY

The Great Galaxy in Andromeda, one of the closest to earth, is still more than two million light years away. It is similar to our own Milky Way.

tion to be certain about either the shape of the Galaxy or the sun's exact position in it, although they had quite a good idea about the solar system's location.

The Mystery of the Universe

RADIO ASTRONOMY HAS CREATED a great controversy about the birth of the universe itself. This stems from mysterious objects called "quasars", the most distant objects ever "seen" by men.

Starting in the early 1960s, radio astronomers began increasingly to recognize signals from space of startling power—so powerful that the

original forces that produced them must have been of incredible energy indeed. Finally, radio telescopes were used to pinpoint the location of some of these objects. When photographed later through optical telescopes, they appeared to be ordinary stars. Because they were producing energy clearly impossible in any one star, yet still looked deceptively like stars, they were called "quasi-stellar radio sources"—since shortened to quasars.

Dr. Maarten Schmidt, a Dutch-born astronomer at the Hale Observatories in California, analyzed the light of one of these quasars, referred to as 3C-273, and found that it was racing away from the earth at fifteen per cent of the speed of light, or about 43,000 miles a second. This, in turn, indicated that this quasar was about 1.5 billion light years away instead of being the faint, nearby star that most astronomers had always assumed. It was found that the light produced by this one object was as much as 100 times more brilliant than the light of an ordinary galaxy—despite all the galaxy's 100 billion glowing stars. Then another quasar, called 3C-48, was found to be receding even faster than 3C-273 and appeared to be some 4 billion light years away. It is felt by some scientists that other quasars may be 12 billion light years away. Light travels at a swift but finite speed, so Dr. Schmidt and his colleagues believe they were seeing quasars as they looked billions of years ago.

Because the behavior of quasars transcends the laws of physics known at present, they are being watched and studied with tremendous interest for their bearing on the important question: How did the universe begin?

Some scientists—the "Big Bang" theorists—insist that the universe began about 10 billion years ago in a huge explosion of densely packed matter which since has formed the stars, galaxies and everything else that exists in cosmic space. The "Steady State" proponents claim that the universe has always existed and is constantly being replenished by new matter condensing into material from energy. A third group, adherents of an "Oscillating Universe" theory, lean to a concept of a universe that expands after a big bang, contracts to an extremely dense state, and then explodes outward again in a never-ending, 82-billion-year cycle.

Of the three, the Steady State theory received the most severe blow following analysis of the first quasars that were studied. Some astronomers, in fact, tend to think that quasars give irrefutable evidence of a great cosmic explosion. Other astronomers still consider the evidence much too uncertain. Quasars do leave many questions unanswered and will go

on provoking bitter controversies among scientists. But if astronomers can find an explanation for the birth of quasars, they may yet be able to unravel the secrets of creation itself—and eventually the ultimate mysteries of matter and energy on earth.

Now: Pulsars

NO LESS PUZZLING than quasars are "pulsars"—diminutive objects in the sky that give off regular, sharp bursts of radio energy. Pulsars are a more recent phenomenon than quasars, and were discovered this way: One day in 1967, at the University of Cambridge in England, scientists heard a sharp radio burst over the radio telescope sounding like "a human sigh". It came again, again and again, in steady, staccato beats. The beats were so regular that they were found to be more exact than the atomic clocks used to time them.

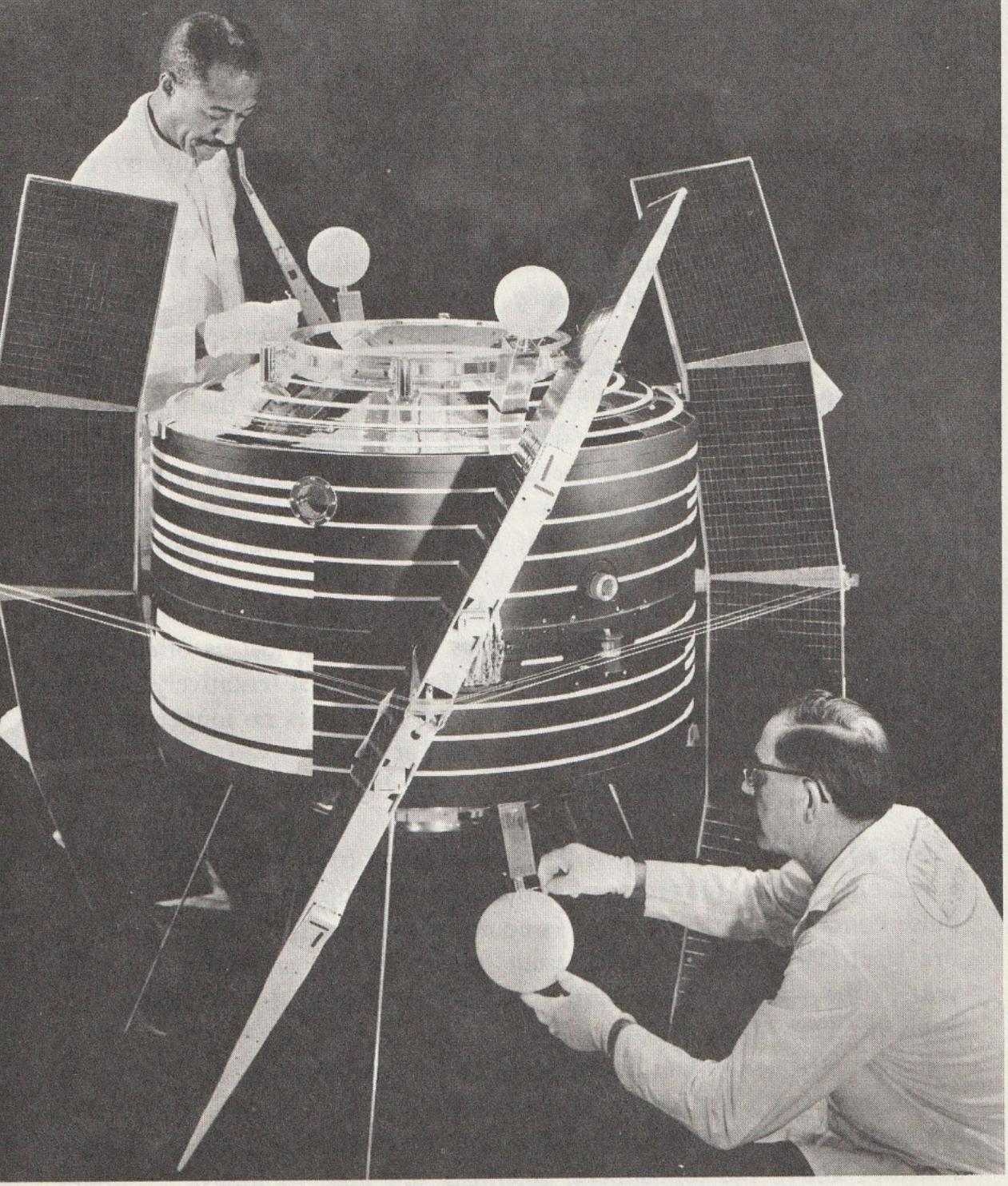
The pulsars were initially estimated to be fifty to 300 light years away in the spiral arm of the Galaxy. Then, later evidence led several British scientists to believe the pulsars may be thirty times further away, and perhaps outside our Galaxy.

The rhythmic pulsation was initially considered to be produced, possibly, by some kind of intelligent life out in space. With fingers crossed, and tongue in cheek, the scientists dubbed the radio sources "LGM", for "little green men".

Now this theory has been discarded. The energy output of the pulsar is so vast as to require a stellar source. A pulsar's energy output is amazing. Every second or so a pulsar unleashes a burst of energy that is the equivalent of several atomic bombs of kiloton yield. Scientists estimate that a postage-stamp-sized speck on a pulsar can generate as much power as all the electrical power plants in the world.

Some pulsars under the scrutiny of atomic clocks have been found to be slowing down. The pulsars' beats range from 3/100 of a second to every two seconds.

The pulsar as an entity is still a puzzle. One theory describes a pulsar as a "white dwarf", a neutron star that has burned up most of its nuclear fuel and has been forced by gravity to collapse into a condensed image of its former self. Another theory holds that a pulsar is a hot gas trapped in a magnetic envelope. Finding the truth of the matter is one more challenge for radio astronomers.



Engineers examine antenna targets on Explorer 38—the first United States radio astronomy satellite. Each of the four antennas was extended to a length of 750 feet in orbit.

Space Astronomy Comes of Age

FOR DECADES, scientists have dreamed of getting above the atmosphere and the ionosphere to get a clearer crack at the cosmos. Now this goal is being achieved by space satellites with instruments that can reach

those regions of the electromagnetic spectrum not picked up by earth-operated telescopes.

The first United States radio astronomy satellite, Explorer 38, was launched in 1968, hauling antennas stretching taller than the Empire State Building to monitor low-frequency radio signals which cannot penetrate the ionosphere. Several years later Explorer 42, an X-ray-observing satellite weighing only 315 pounds, provided scientists with the first complete and sensitive depiction of the swatch of X-rays pervading the universe.

Astronomers hope that the data from instrumented satellites will lead to the discovery of the high energy processes which govern the evolution of stars and galaxies, and increase their knowledge of those regions near the center of the Milky Way that have heretofore been inaccessible by radar, radio or optical telescopes.

Explorer 42 detected a pulsar, identified as Cygnus X-1, which generates X-ray pulses at the rate of fifteen pulses per second, just as other pulsars give off radio emissions. Cygnus X-1 contains the first tentatively identified "black hole", so named because it is full of dead stars no longer giving off light or radiation. While black holes cannot be observed, they suck the atoms out of stars until they emit X rays near the black hole, thus revealing its existence.

Pulsed X rays at the rate of thirty per second from the Crab Nebula, an enormous cloud of glowing gas, also were picked up by Explorer 42. "Each pulse contains as much energy as could be produced by collecting the entire electrical output of our present terrestrial civilization for 10 million years," the National Aeronautics and Space Administration noted in its announcement of the discovery.

Space astronomy has accentuated what astronomers are calling the "multiwavelength approach" to understanding the universe. By receiving a variety of forms of radiation from both earthbound telescopes and from satellites above the ionosphere, scientists are able to interpret radiation from the whole gamut of the electromagnetic spectrum (gamma rays, X rays, ultraviolet radiation, visible light, infrared and radio waves).

This "multiwavelength approach" is evident in the construction of the world's largest radio astronomy telescope in New Mexico, even while the United States space agency proceeds with its plans for future missions to visit every one of the sun's captive worlds except Pluto over the next decade.

The new giant telescope in New Mexico costs 76 million dollars. Known as the Very Large Array, it is scheduled to be completed in 1981 on an

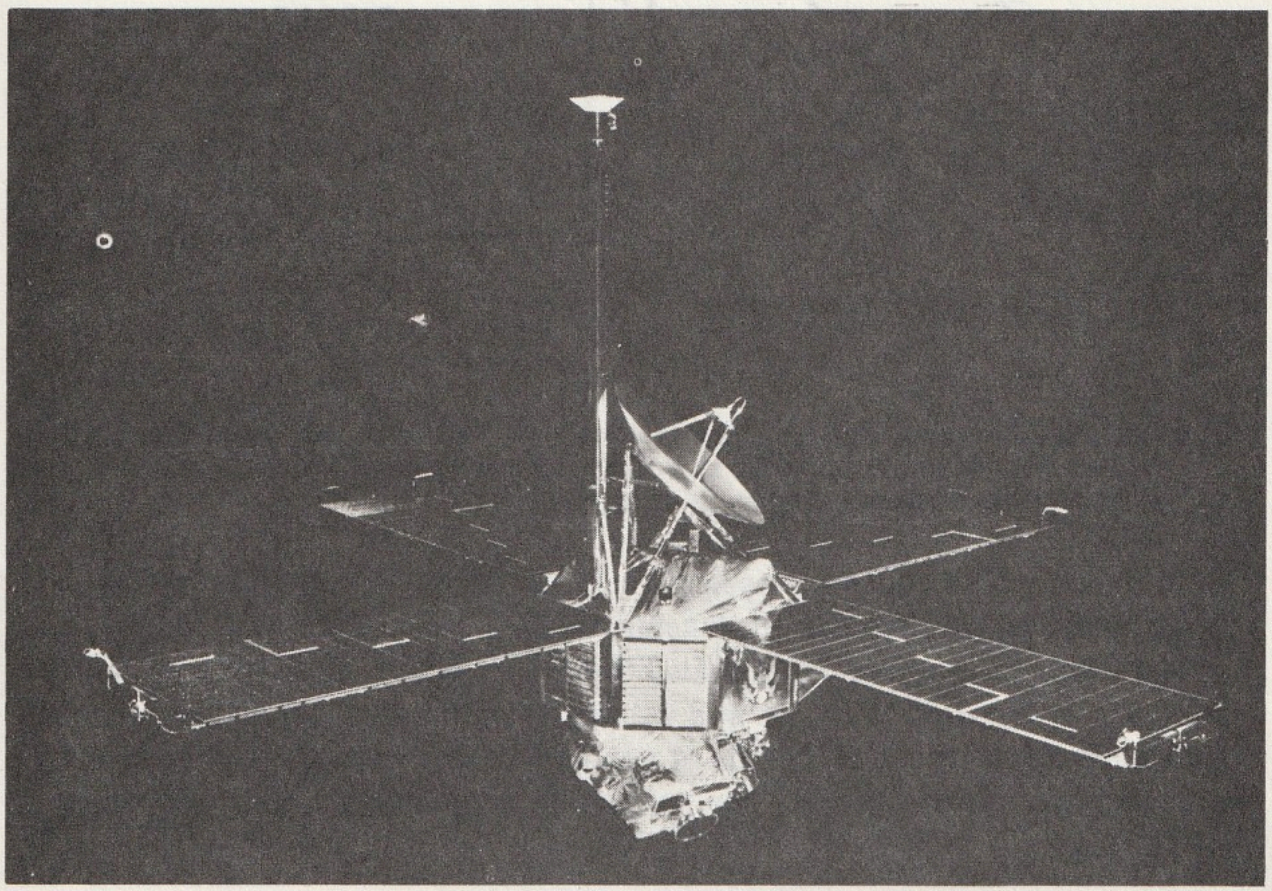
arid ranch. It will have twenty-seven dish-shaped radio telescope antennas (eighty-two feet in diameter and ninety-two feet high) that may be moved to any of 100 observing stations along a thirty-seven-mile railway. It will provide scientists with the first clear picture of the heart of our galaxy, as well as other galaxies in the universe, where there is a complex ensemble of radio emitting regions concealed from optical telescopes by dense dust clouds.

"The V.L.A. will be for the young science of radio astronomy what the 200-inch Palomar telescope was for ordinary astronomy when it was completed in 1949," according to one astronomer.

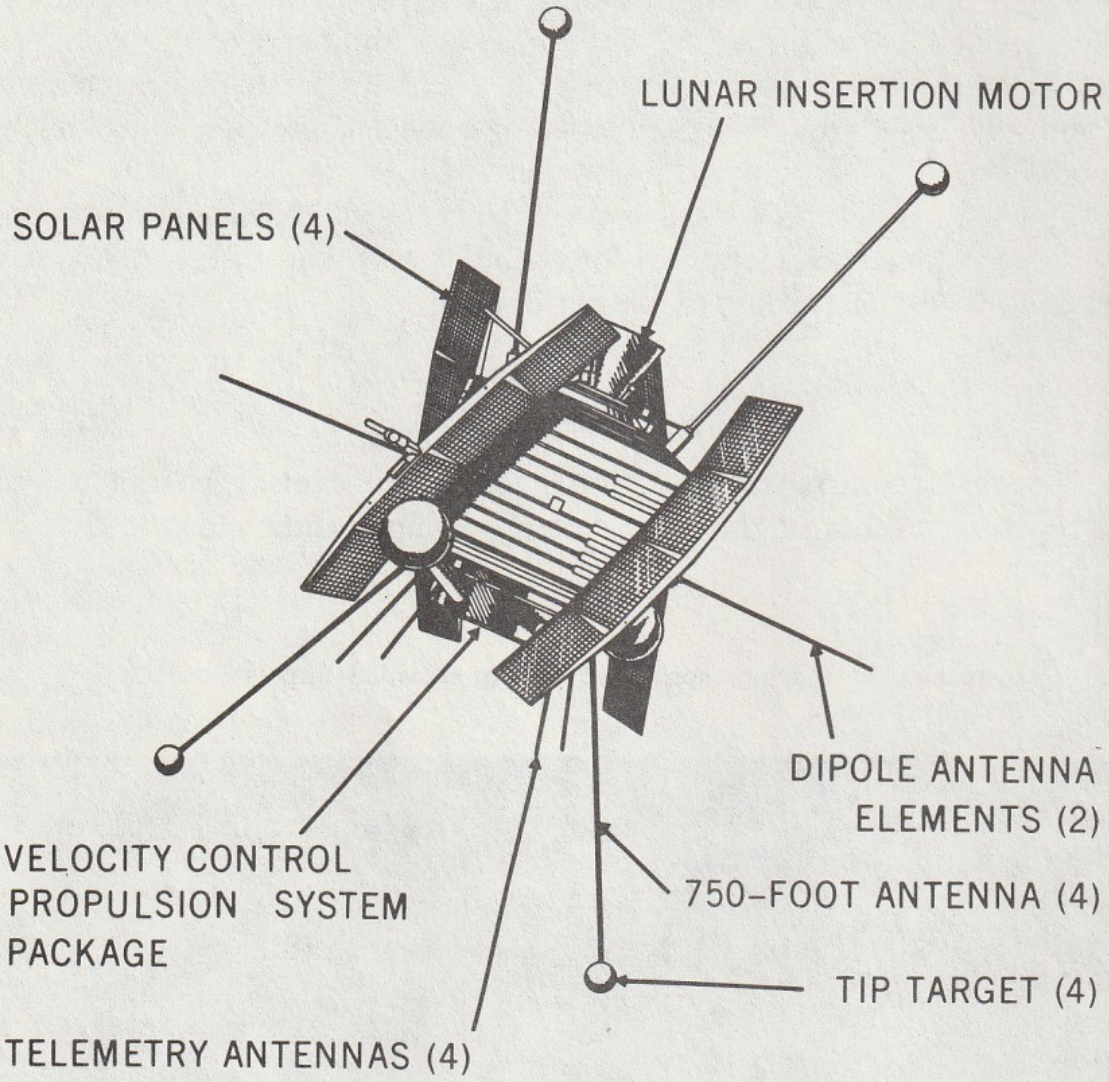
The Far Reaches

UNMANNED AUTOMATED SPACE PROBES will explore all but the farthest reaches of the solar system, giving earthbound scientists new

Instrumented Mariner spacecraft which provided important data on the planet Mars.



RADIO ASTRONOMY EXPLORER – B



This satellite gave scientists important data on the little-understood low-frequency radio noises in our galaxy. The telemetry antennas, when fully deployed, are as tall as the Empire State Building.

information about the solar system including that "empty" space that is undisturbed by the presence of planetary bodies.

For example, Mariner 10 provided some spectacular close-up images of Mercury in April of 1974, as well as vital scientific data about the planet which has spent its entire lifetime of nearly 5 billion years very close to the intense radiation of the sun. The spacecraft approached within 460 miles of Mercury.

One of the most exciting missions planned is the release of huge metal floats in the atmosphere of Venus. Armed with radar, laser altimeters and other devices, the floats will chart conditions of the dense Venusian atmosphere as they bob about in it. The United States also may launch a spacecraft to land on Venus, which in addition to television cameras, will carry instruments to monitor seismic disturbances, weather and other phenomena.

The first of the two Viking probes is scheduled to land on Mars in 1976 with an array of instruments to look for the first concrete signs of extraterrestrial life.

There are no plans to try to penetrate Jupiter's crushing atmosphere and land on its surface, but in 1981 two spacecraft may be sent to study it from an orbit of about 90,000 miles.

In 1985, a pair of spacecraft might orbit Ringed Saturn, travelling right through the rings themselves. Instrumented probes prior to this will tell scientists whether the icy chunks comprising the rings would be likely to destroy the spacecraft.

Other missions may add to our knowledge of Titan, Uranus and Neptune. The reason none is planned to Pluto is because it is just too far away—never less than 2.8 billion miles.

These space probes are expected to contribute valuable data to astronomers who already have discovered several thousand sources of radio emissions in outer space. They expect that with improved capability in monitoring radiation in the universe it would not be surprising to find 100,000 different emission sources. In years to come some of those surprises might well come from a billion-dollar proposal to launch into space an optical telescope—one that would be more than half as large as the 200-inch scope on Mount Palomar in California.

Certainly we can be definite about one thing—our window on the universe is an ever-expanding one and astronomers are bursting with anticipation over surprises that surely await them.

Glossary of Terms Used in Radio and Radar Astronomy

—Compiled with the aid of the American Institute of Physics—

Antenna. That part of a radio apparatus that receives waves from space, or radiates waves into space.

Array. Any specific arrangement of antenna elements (dipoles, etc.) designed to produce a particular pattern.

Astronomical Unit. The mean distance of the earth from the sun. This distance is about 93 million statute miles.

Corona. The tenuous outer envelope of gas surrounding the sun.

Cosmic Rays. Extremely high-energy particles which occasionally impinge on the earth.

Dipole. Generally, any device having unlike charges at its opposite ends. A common active part of an antenna system.

Dish. A concave reflector of radio waves. It collects radiation over its geometric aperture and reflects it to the focus, where the antenna is placed.

Frequency. The number of oscillations per second of an electromagnetic wave.

Galaxy. A system in space usually containing upwards to 10 billion stars. Includes interstellar gas and its associated magnetic fields and cosmic rays.

Light Year. The distance light travels in one year at the rate of 186,000 miles per second. The total distance is about six million million miles.

Nebula. A cloud of gas, possibly including dust, in outer space.

Pulsar. Object in the sky that emits regular bursts of radio energy.

Quasar. A contraction of "quasi-stellar radio source".

Radio Source. A particular point or area in the sky from which radio waves are received.

Radio Telescope. Any type of antenna system designed to receive radio radiation from the sky. It often bears little resemblance to an optical telescope.

Spectrum. Comprises gamma rays, X rays, ultraviolet rays, light (visible) rays, infrared rays, radio waves. All astronomical observations involve the use of the spectrum.

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